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THE EFFECTS OF CLIMATE AND GRAZING PRACTICES ON SHORT-GRASS PRAIRIE VEGETATION

in Southern Alberta and Southwestern Saskatchewan

By

S. E. CLARKE, E. W. TISDALE
and
N. A. SKOGLUND

EXPERIMENTAL FARMS SERVICE

Range cattle beside reservoir on typical short-grass prairie at the Dominion Range Experiment Station, Manyberries, Alberta

Published by Authority of the Hon. James G. Gardiner, Minister of Agriculture,
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The Effects of Climate and Grazing Practices on Short-Grass Prairie Vegetation in Southern Alberta and Southwestern Saskatchewan

BY

S. E. Clarke, E. W. Tisdale and N. A. Skoglund

INTRODUCTION

The extensive grazing lands of Western Canada constitute a natural resource of great importance. Approximately 40 million acres in the three Prairie Provinces of Alberta, Saskatchewan and Manitoba are used for the grazing of live stock. These prairie ranges provide the bulk of the forage consumed by a live-stock population which comprised 1,815,000 horses, 3,564,000 cattle and 1,618,000 sheep in 1941. The manner in which these grazing resources are utilized is naturally a matter of national concern.

Prior to the advent of the dryland farmer into western Saskatchewan and Alberta, large areas of free, open range were available. The native grass cover provided an abundance of feed for live stock in the summer months and also during the winter except when climatic conditions were unusually unfavourable. Under these circumstances the production of live stock on the range was an attractive undertaking and the industry expanded rapidly.

With further settlement of the country most of the more productive lands were brought under cultivation, mainly for cereal production. Native pastures were confined more and more to areas which, by reason of their climate, soil or topography, were not suitable for the production of cultivated crops. In fact, under the stimulus of high prices for wheat during the first World War, the native sod was broken in many areas which subsequent experience showed to be entirely unfit for cultivation. Several million acres of this submarginal land were later abandoned and allowed to go back to weeds and eventually to grass. In some cases artificial reseeding with suitable introduced forage species was employed in order to speed up the normally slow return to a grass cover.

With the marked decrease in areas available for grazing and the introduction of a lease system in place of free range, over-stocking of native pastures became all too common. The ill effects of this over-crowding of the ranges were accentuated by drought conditions in the post-war period, and shortage of grass combined with low prices to produce a depressed condition in the ranching industry. Much over-grazing of ranges occurred, and it became evident that there was danger of widespread depletion of the grazing resources of the prairies unless steps were taken to remedy the situation. These undesirable conditions led to requests by the stockmen for an investigation of the native pasture lands of the west. It was felt that the matter of securing proper utilization of the ranges and satisfactory lease regulations could be solved only when basic information was available regarding the nature and grazing capacity of the native vegetation.

In response to the requests of the stockmen, the Experimental Farms Branch of the Dominion Department of Agriculture was authorized to investigate conditions in the prairie range areas. In 1926 a survey was made of the main ranching districts to determine the nature of the problems confronting the industry and to formulate plans for an intensive study of these problems. As

a result of the survey the establishment of a range experiment station in southeastern Alberta was recommended to the Dominion Government. In 1927 a site was selected for the Dominion Range Experiment Station, the first of its kind in Canada. The area chosen for the experimental work consisted of some 18,000 acres of range land situated near the village of Manyberries in the southeastern corner of Alberta. These lands constitute the greater part of township 2, range 4, west of the fourth meridian. The vegetation consists of typical native grassland, none of which had ever been cultivated. The land was fenced off into a number of fields of different sizes for testing various systems and intensities of grazing. Much of the area had been of little use for grazing previously due to the lack of water for live stock. Therefore, an extensive program of water development was necessary before the experimental studies could be initiated.

In 1928 a comprehensive program of investigational work was begun. The main objective was the acquiring of accurate and detailed information regarding the nature and proper utilization of the native vegetation. The projects included both range forage and animal husbandry studies.

The plant studies included fundamental investigations of the native vegetation and applied studies in range management. The former were rendered necessary by the fact that practically no data were available concerning the nature of the plant cover found in the area. The program included identification of the native flora and studies of the vegetative characters, growth development, palatability and nutritive value of the principal native plants. The effects of climate on plant growth and the relative productivity of different species were investigated. Studies of plant communities included determination of the distribution, botanical composition, productivity and successional relationships of the main associations. The data obtained on vegetative characters and nutritive value of the native plants are being published separately.

The range management projects included studies of the effects of different systems and intensities of grazing upon the botanical composition and productivity of various types of native pasture. The effects of complete protection from grazing were determined as a check on the grazed fields. Clipping experiments were conducted in which different grazing practices were simulated by cutting of the native vegetation. These tests, while not duplicating entirely the effects of grazing, were particularly valuable in providing a direct measure of forage yield obtained with different intensities and times of clipping. Data on grazing capacity were obtained by studies of the response of the plant cover in pastures grazed at different intensities, and by yield determinations on various types of range vegetation.

The animal husbandry projects included studies of the response of range cattle to different methods and intensities of grazing, the relative gains in weight made by different classes and ages of stock, and the relation of summer grazing to winter maintenance. Other projects included the development of various types of watering places and the preservation of fence posts.

The nature of the projects conducted and the results obtained in a study of the native grasslands and their utilization at the Dominion Range Experiment Station, Manyberries, Alberta, during the 12-year period 1928 to 1939 inclusive, are presented in this publication.

DESCRIPTION OF THE EXPERIMENTAL AREA

Topography

The topography of the Station lands is mostly undulating to rolling, and the area is traversed by a number of steep-banked watercourses known as coulees. Drainage is to the south into the Milk River, which crosses the

International Boundary at a point about seven miles south of the Station headquarters. The coulees are normally dry, carrying water only in the spring of the year or after heavy rains. The altitude of the area varies from 3,000 to 3,200 feet.

Climate

The climate is characterized by scanty precipitation, a high rate of evaporation, great extremes of temperature, high and frequent winds and long hours of sunshine. Climatic data were obtained at Station headquarters over the 11-year period 1929 to 1939 inclusive. The average annual precipitation for these years was 10·7 inches, half of which fell during the period April 1 to July 31. Evaporation from a free water surface for the period May 1 to September 30 averaged 33 inches. The mean monthly temperature varied from 10·8° F. in January, the coldest month, to 69° F. in July, the warmest month. Sudden, marked changes in temperature were common at all seasons. The prevailing west and southwest winds were usually hot in summer and dried out surface soil moisture rapidly. In winter the warm "chinook" winds from the same quarter frequently removed the snow cover even in midwinter. The average daily amount of wind for the period April 1 to September 30 was 268 miles. The average period of bright sunshine during these same months was 8·6 hours daily. The frost-free period averaged 124 days, but there was great variation from year to year.

A comparison of precipitation and evaporation records from the Experiment Station with those from other typical prairie localities is presented in table 1.

TABLE 1.—AVERAGE PRECIPITATION AND EVAPORATION DATA FOR CERTAIN PRAIRIE LOCALITIES 1929 TO 1939

Place	Precipitation in Inches		Evaporation Inches	Ratio of Precipitation to Evaporation
	Annual Total	April - July		
*Manyberries, Alta.	10.7	5.3	33.0	0.32
*Lethbridge, Alta.	15.3	6.9	26.6	0.57
Medicine Hat, Alta.	12.4	5.6	....	....
*Swift Current, Sask.	12.2	6.3	32.4	0.38

*Records from Dominion Experiment Stations.

These data indicate that climatic conditions at the Manyberries Station are slightly more arid than at most other points in the drier parts of the prairies. The period 1929 to 1939 was predominantly one of drought, and the figures in the above table differ somewhat from the long-term averages for the stations where such records are available. For instance, the average precipitation at the Swift Current Experimental Station during the 20-year period, 1922 to 1941 was 13·2 inches, while the average evaporation rate during that period was 30 inches.

Soil

Most of the soils of the area have been formed from glacial till derived mainly from the native sandstones and shales of the region. In many places the mantle of glacial material is thin or lacking, and exposures of the parent rock which belongs to the Belly River formation are common. The area lies within the brown soil zone as might be expected from the dry climatic conditions and relatively sparse plant growth. The upland soils vary in texture from sandy loam to silt loam and are characterized by the presence of a layer of carbonate

concentration occurring at an average depth of about 12 inches. This hardpan layer marks the depth to which moisture usually penetrates. The soils of the lowland areas are chiefly alluvial in origin and the common textures are silt and clay loam. A feature of the soils of the region is the presence of numerous eroded pits known as blow-outs. These are areas from which varying amounts of the "A" horizon of the soil have been removed, exposing the compact and relatively impermeable "B" horizon. Similar eroded spots and the processes connected with their formation have been described in North Dakota by Kellogg (7). Plant growth is usually sparse or lacking on these blow-out areas (figure 2).

FIG. 1.—Eroded Badlands along bank of coulee at the Range Experiment Station, Manyberries, Alberta. Note lack of plant cover on light-coloured areas of exposed bed-rock.

Soil erosion is evident along the banks of the coulees and in the areas known as badlands. The latter occur in areas of rough topography where the native rock of the region is exposed. Erosion is fairly rapid and moisture penetration slight in this material, particularly where shales are common. The conditions produced on these areas are highly unfavourable for the development of either a plant cover or a normal soil profile, and a more or less permanently barren state usually results.

A study was made of the chemical composition of the soils on the Station pastures. Data obtained from the analyses of samples from the surface six inches from three typical areas are presented in table 2.

TABLE 2.—CHEMICAL COMPOSITION OF TYPICAL BROWN SOILS

Type	Nitrogen	Phosphorus		Potassium		Calcium	Magnesium
		Total	Available	Total	Available		
Upland soil, sandy loam..	0.150	0.063	0.020	0.473	0.028	0.588	0.921
Soil from alluvial flat, silty loam..............	0.095	0.062	0.010	0.651	0.021	1.792	1.026
Blow-out area, silty clay loam....................	0.110	0.051	0.012	0.540	0.016	0.798	0.439

All figures for plant nutrients are given on a percentage basis.

It will be noted that all three soils were low in nitrogen and available phosphorus, with the alluvial and blow-out types poorest in this regard. All were well supplied with calcium and magnesium, while only the blow-out type was low in available potassium. The pH values were 7·7 for the normal, upland soil, 7·9 for the blow-out soil and 8·2 for the alluvial silt loam.

These results are in general agreement with the average figures given for typical brown soils of comparable texture in the soil survey reports for south-eastern Alberta (14) and for Saskatchewan (11). The soils of the brown zone are usually lower in nitrogen and phosphorus content than are those of the dark brown and black zones where moisture conditions are more favourable and plant growth more luxuriant.

FIG. 2.—Typical blow-out spot on short-grass prairie. Note light colour and compact surface of the exposed "B" soil horizon. Plants of *Agropyron Smithii* are beginning to invade the area.

The concentration and nature of the alkali salts present in the soils of the region are not usually such as to inhibit plant growth. Only in poorly-drained depressions do high salt concentrations occur, and there are few areas which do not possess some plant cover.

The moisture-retaining capacity of most of the soils of the area is fairly high, but absorption of water is not usually rapid because of the compact structure. Considerable run-off occurs during heavy rains, especially on the badlands, over-grazed pastures, and other areas where a well developed plant cover is lacking.

On the whole the soils of the region are sufficiently fertile to produce good yields of native forage or of other crops when sufficient moisture is available. Soil moisture, not fertility, is the principal limiting factor for plant growth.

Vegetation

The vegetation of the area consists of a type of grassland designated as short-grass prairie (2). This may be considered as a xeric type of the mixed prairie association described by Weaver and Clements (13). In short-grass prairie

one of the two principal species, *Bouteloua gracilis,* as well as other dominants including *Poa secunda* and *Carex filifolia* are short-grass forms. The mid-grass dominants which comprise *Stipa comata, Agropyron Smithii* and *Koeleria cristata* tend to be dwarfed in stature in this association.

In typical mixed prairie, as found in Western Canada, the short-grass species are less abundant than in short-grass prairie, while the mid-grasses are taller and more abundant. Certain dominants of the mixed prairie, including *Stipa spartea* and *Festuca scabrella* are rare or lacking in the short-grass prairie. This type of grassland is associated with climatic conditions slightly more arid than those found where typical mixed prairie prevails. Short-grass vegetation occupies the drier portions of the brown soil zone.

The plant cover of the Station lands is typical of that occurring generally on the drier portions of the Canadian prairies. Similar vegetation occupies most of the land contained in a roughly triangular area based on the International Boundary and extending from a point south of Moose Jaw, Sask., on the east to the vicinity of Lethbridge, Alta., on the west. On the north the area extends approximately to township 31 on the fourth meridian. Included within this triangle, but differing in vegetation type are a number of areas such as the Cypress Hills and the Great Sandhills (plate 1).

METHODS

The botanical composition, density and forage yield of the native plant cover was studied chiefly by means of quadrats, exclosures and clipped plots.

Quadrats one square metre in size were found most satisfactory for general use, although some perquadrats were established for special studies of certain forbs and shrubby species where the individual plants were fairly large. On the metre quadrats, the number of plants of each species present, their average height, vigour and seed production were all recorded. The basal area occupied by each species was determined by means of either the pantograph chart or area list methods (6). In the former method, the position and area of each individual plant was mapped to scale by means of a pantograph operated on a low stand. From this quadrat map the area occupied by each plant and each species was determined later using transparent squared paper laid over the field sheet. The area list method involved estimation of the area occupied by each plant by means of a square metre frame divided by cross wires into square decimetres, or by the use of an area list ruler of the type described by Pearse (8).

Permanent quadrats were used in preference to temporary plots for most of the studies. On the larger fields (500-3,800 acres) these quadrats were established at the rate of approximately one per 25 acres. In small pastures (50-400 acres) the rate was increased to one per 10 acres, with a minimum of 10 quadrats in any field regardless of size. Because of the great variation in plant cover within the various pastures, and of the large area of the fields in relation to the number of quadrats that could be established, selection of sites was considered preferable to strictly random location. Once a site was chosen, the exact spot for the quadrat was picked at random. The location of each quadrat was marked permanently by means of 8-inch iron spikes driven in at each corner and by a square iron stake. This stake was driven in at a point 7 yards from one corner of the quadrat, in line with one of the diagonals, and was allowed to project about 15 inches above the surface of the ground. The location of the quadrat was thus marked without doing anything which would interfer with normal grazing of the area by live stock.

All quadrats were re-charted every 3 to 4 years in order to determine the nature and extent of any changes which might have occurred in their plant cover. By averaging the data obtained from a considerable number of quadrats, reliable data were obtained concerning the effects of grazing practices, climatic fluctuations, or other factors upon the vegetation.

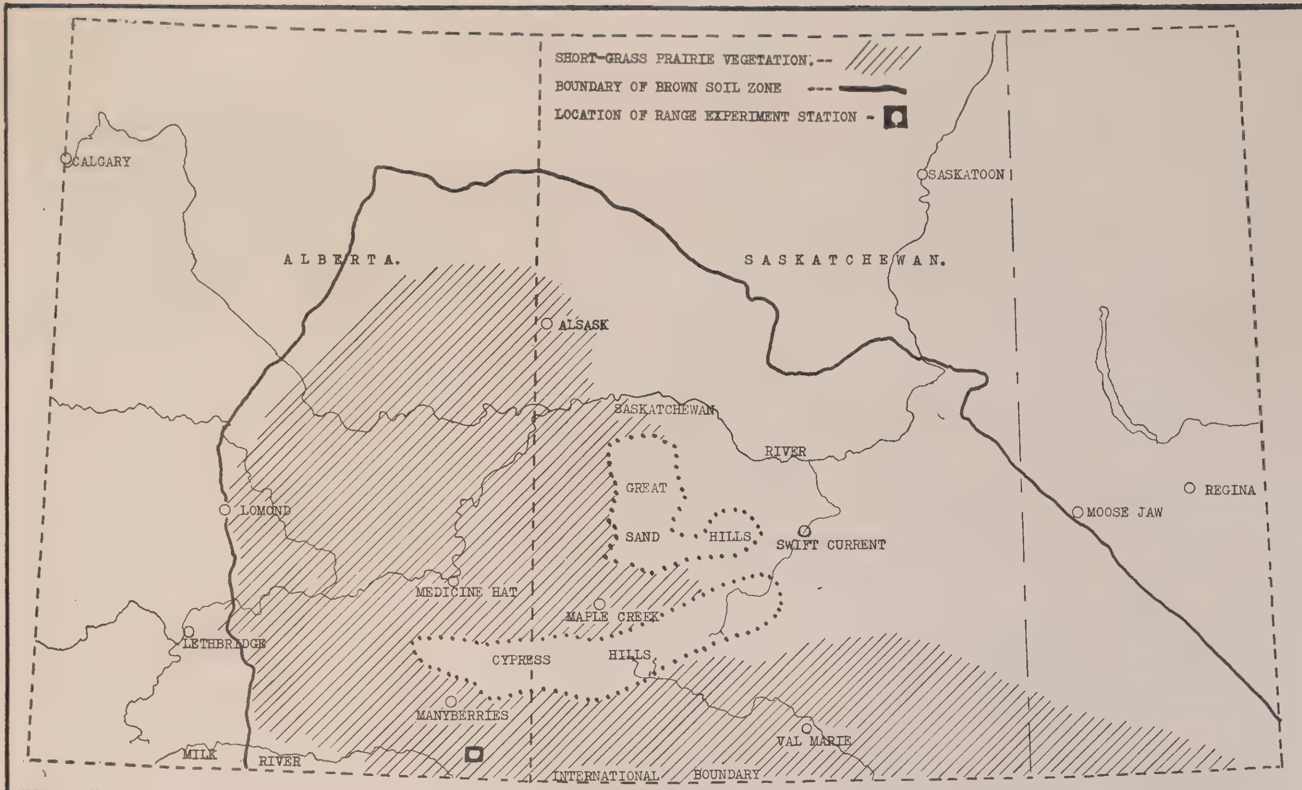

Plate 1.—Map of southern Alberta and Saskatchewan showing extent of short-grass prairie area.

A number of permanent fenced exclosures were established on representative areas in all of the experimental pastures. These plots were 4 square rods in area and were enclosed by an ordinary four-strand barbed wire fence. In addition, an area of about 200 acres located near the Station headquarters and containing vegetation representative of all the main plant communities was fenced off and protected from grazing. The purpose of these exclosures was to facilitate studies of the behaviour of ungraded vegetation as compared with the response of grazed pastures. In addition, these fenced plots served as sites for clipping studies and other projects requiring protection from live stock.

Clipped plots were used for testing the effects of different frequencies and dates of cutting on the vegetation and for determining the productivity of different plant species and communities. Most studies of the former type were conducted on the 200-acre exclosure, where plots of several square rods in extent were clipped with a lawn mower. The use of a lawn mower did not prove altogether satisfactory, especially on certain areas where the surface soil was very loose. Eventually smaller plots clipped by hand were substituted for the larger plots in most cases. Where the lawn mower was used, yield tests were taken on a portion of each plot with hand clippers just prior to cutting with the mower. The plots used for productivity studies ranged in size from one to six square metres, and were all clipped by hand.

FUNDAMENTAL PLANT STUDIES

Investigations of the native flora, the relative abundance and productivity of the principal species and the nature of the main plant communities were conducted during the period, 1928 to 1939. Summaries of the results of these various projects are presented in the following section.

Native Flora

Taxonomic studies were begun as soon as the Station was established and were continued until practically every species of vascular plant growing on the pastures had been identified and a specimen placed in the herbarium. Collections were made from many other range areas as well. A list of the principal plant species occurring on the experimental area is presented in table 3.

TABLE 3.—PRINCIPAL PLANT SPECIES OCCURRING ON THE EXPERIMENTAL AREA

Family	Scientific Name	Common Name
	Grasses and Grass-like Plants	
Poaceae	Agropyron dasystachyum (Hook) Scribn	Northern wheatgrass.
"	Agropyron Smithii Rydb	Western wheatgrass.
"	Bouteloua gracilis (H.B.K) Lag	Blue gramagrass.
"	Calamagrostis montanensis Scribn	Plains reedgrass.
"	Deschampsia caespitosa (L.) Beauv	Tufted hairgrass.
"	Distichlis stricta (Torr.) Rydb	Alkali grass.
"	Hordeum jubatum L	Wild barley.
"	Koeleria cristata Pers	Junegrass.
"	Muhlenbergia cuspidata (Torr.) Rydb	Prairie muhlenbergia.
"	Muhlenbergia squarrosa (Trin.) Rydb	Mat muhlenbergia.
"	Poa Canbyi (Scribn.) Piper	Canby's bluegrass.

Family	Scientific Name	Common Name
Poaceae	Poa secunda Presl.	Sandberg's bluegrass.
"	Puccinellia Nuttalliana (Schultes) Hitch.	Nuttall's alkali grass.
"	Spartina gracilis Trin.	Alkali cordgrass.
"	Stipa comata Trin. & Rup.	Common speargrass.
"	Stipa viridula Trin.	Green speargrass.
Cyperaceae	Carex Eleocharis Bailey	Involute-leave sedge.
"	Carex filifolia Nutt.	Niggerwool.
"	Eleocharis palustris (L) R. & S.	Spike rush.
Juncaceae	Juncus ater Rydb.	Baltic rush.
Liliaceae	Zygadenus gramineus Rydb.	Death camas.
	Broad-leaved Herbaceous Species (Forbes)	
Polygonaceae	Eriogonum flavum Nutt.	Yellow eriogonum.
Corrigiolaceae	Paronychia sessiliflora Nutt.	Whitlow wort.
Leguminosae	Cnemidophacos pectinatus (Hook) Rydb.	Narrow-leaved vetch.
"	Diholcos bisulcatus (Hook) Rydb.	Two-grooved vetch.
"	Orophaca caespitosa (Nutt) Britton	Dwarf vetch.
"	Oxytropis gracilis (A. Nels.) K. Schum.	Yellow loco.
"	Thermopsis rhombifolia (Nutt) Richards.	Golden bean.
Malvaceae	Sphaeralcea coccinea (Nutt.) Rydb.	Scarlet mallow.
Cactaceae	Opuntia polyacantha Haw.	Common cactus.
Polemoniaceae	Phlox Hoodii Richards.	Dwarf phlox.
Compositae	Antennaria microphylla Rydb.	Dwarf everlasting.
"	Artemisia frigida Willd.	Pasture sage.
"	Chrysopsis villosa (Pursh) Nutt.	Golden aster.
"	Gutierrezia diversifolia Greene	Broom weed.
"	Solidago missouriensis Nutt.	Dwarf goldenrod.
	Shrubs and Shrubby Species	
Salicaceae	Salix interior Rowlee (and other species of Salix)	Sandbar willow.
Chenopodiaceae	Atriplex Nuttallii S. Wats.	Salt sage.
"	Eurotia lanata (Pursh) Moq.	Winter fat.
Rosaceae	Rosa Macounii Greene (?)	Wild rose.
Caprifoliaceae	Symphoricarpos occidentalis Hook.	Snowberry.
Compositae	Artemisia cana Pursh.	Sagebrush.
"	Artemisia gnaphalodes Nutt.	Dwarf sagebrush.
"	Artemisia longifolia Nutt.	Long-leaved sage.
"	Chrysothamnus frigidus Greene	Rabbit brush.
	Pteridophytes	
Selaginellaceae	Selaginella densa Rydb.	Little clubmoss.

Most of the more abundant species belong to the Poaceae and Compositae. Families of secondary importance included the Cyperaceae, Chenopodiaceae and Leguminosae. While the species listed above comprise only a portion of the flora of the Station lands, they constitute almost the entire plant cover.

Relative Abundance of Species

Although a considerable number of plant species occurred on the experimental area, relatively few were present in sufficient abundance to be rated as important constituents of the plant cover. Data on relative abundance were obtained by means of several hundred metre quadrats distributed over the Station pastures. In determining relative densities, the technique was varied to suit different life forms. The basal area of bunch and mat-forming grasses was measured or estimated directly. In the case of rhizomatic species, individual shoots were counted, and a fixed area allowed for each. The density of forbs and shrubs was determined by crowding the shoots of each individual plant together until the ground below was shaded completely. The area so occupied was considered as the cover for that plant. The average densities determined for the various species from a study of 475 metre quadrats are included in table 4.

TABLE 4—AVERAGE DENSITY OF PRINCIPAL SPECIES ON THE STATION PASTURES

Name of Species	Density in Per Cent	Proportion of Total Cover in Per Cent
Bouteloua gracilis	4·09	37·8
*Agropyron Smithii	1·19	11·0
Stipa comata	2·23	20·6
Koeleria cristata	0·72	6·6
Poa secunda	0·36	3·3
Carex filifolia	0·23	2·1
Total Grasses and Sedges	8·82	81·4
Artemisia frigida	0·72	6·6
Phlox Hoodii	0·56	5·2
Opuntia polyacantha	0·15	1·3
Sphaeralcea coccinea	0·06	0·6
Gutierrezia diversifolia	0·05	0·5
Total Forbs	1·54	4·2
Eurotia lanata	0·33	3·0
Artemisia cana	0·09	0·8
Atriplex Nuttallii	0·06	0·6
Total Shrubby Species	0·48	4·4
Selaginella densa	11·88	
Total (less Selaginella)	10·84	100·0

*Due to the difficulty of distinguishing between Agropyron Smithii and A. dasystachyum in the leaf stage, and to their great similarity in habitat, growth development, forage yield, etc., all data for these two species have been grouped under the name A. Smithii in this report.

All other species occurred so rarely on the quadrats that their density was negligible, and hence they are omitted from the above table. The average plant cover, excluding the dwarf *Selaginella densa,* was only 10·8 per cent. This rather sparse stand appeared to represent a normal condition under the climatic conditions prevailing in the Manyberries area. It will be noted too that well over one-third of the cover was contributed by the short grass, *Bouteloua*, while other low-growing species were common also. It must be remembered that these data for cover were determined on basal area, and hence are lower than measurements of foliage cover would have been. The importance of grasses and sedges is shown by the fact that they comprised about 80 per cent of the total plant cover, *Selaginella* excluded. The stature of this latter species was so small and its water and nutrient requirements so slight that it did not exert much influence despite its great basal area.

Productivity of the Main Forage Species

An intensive study was made of the yielding ability of the principal native forage species of the area in relation to their basal cover. The method consisted in determining the basal area and yield of large numbers of individual plants of each of the species being studied. On representative areas fully developed plants were selected at random, the basal area of each determined by the area list method, and the forage harvested by means of hand clippers. The grazing habits of the cattle were simulated in taking these yields, by clipping the grass species closely but harvesting only the young, tender shoots of shrubby plants. The clippings from all the plants of one species obtained in a season were bulked and the air-dry weight of forage determined. Yields were calculated on total basal area clipped rather than on numbers of plants. This study was conducted over a period of several years (1932 to 1939) and on different vegetation and soil types in order to arrive at average yield data for the principal range species.

From these data, forage yield factors were developed for the different species using *Stipa comata* as a standard. With the productiveness of *Stipa* taken as unity the forage yield factor for each of the other species was calculated by comparing its average yield with that produced by an equal area of *Stipa*. Thus the low-growing *Bouteloua gracilis* was found to have a forage yield factor of only 0·33 as compared with 1·00 for *Stipa* and 1·28 for *Agropyron Smithii.* Carrying the calculations a step farther, a figure designated as the forage yield index was derived for areas where the basal cover of the component species had been determined. This was done by multiplying the forage yield factor of each species by its basal cover. The total of the forage yield indices for the component species of any pasture area represented the density of all the forage species converted into terms of *Stipa* cover. The average yield of *Stipa* was found to be equivalent to 4,500 pounds per acre of air-dry forage on the basis of a 100 per cent stand. The actual basal cover of this species was usually about 10 per cent, but computation of yield for a complete stand was necessary in order to place all calculations on a percentage basis.

Using the data and procedure outlined above, the forage-producing ability of any range area could be determined if the data on botanical composition and basal cover were available. Such information was obtained on several hundreds of metre quadrats, hence their productive value and the average forage value of the fields which they represented could be determined. Thus the determination of the productive capacity of any vegetational area involved the following procedure:

1. Determination of the basal area occupied by each of the forage species.
2. Calculation of the forage yield index for each species by multiplying its forage yield factor by the basal area occupied. The forage yield factor of *Stipa comata* was taken as unity, and the other species were rated according to their productive capacity as compared to that of *Stipa*.

3. Summation of the forage yield indices of all species on the area.

4. Determination of the forage-producing ability of the area by multiplying the total forage yield index by the average yield of a 100 per cent stand of *Stipa comata,* which was taken to be 4,500 pounds of air-dry forage.

An example of the application of the method to the data from a metre quadrat on one of the Station pastures is given as follows:
Quadrat D-120.

Species	*Basal Area*		*Yield Factor*		*Yield Index*
Bouteloua gracilis...........	3·80	x	0·33	=	1·254
Stipa comata	2·55	x	1·00	=	2·550
Agropyron Smithii	0·17	x	1·28	=	0·217
Koeleria cristata............	0·45	x	0·97	=	0·436
Eurotia lanata	0·95	x	1·48	=	1·406
Total of Forage Yield Indices				=	5·864

Forage yield—$\frac{5 \cdot 854 \times 4{,}500}{100}$ (yield of 100 per cent *Stipa* stand 263·8 pounds per acre

The average density and yield of each of the main forage species on the experimental area was worked out by this method, using data obtained from 180 area list quadrats distributed over the various plant types. A summary of the results for the 8 main species is presented in table 5.

TABLE 5.—AVERAGE BASAL AREA AND PRODUCTIVITY OF MAIN FORAGE SPECIES

Species	1 Density in per cent	2 Forage Yield Factor	3 Forage Yield Index	4 Average Yield (lbs./acre)	5 Composition of Forage (per cent)
BOUTELOUA GRACILIS....................	4·09	0·33	1·35	60·8	19·8
STIPA COMATA...........................	2·23	1·00	2·23	100·4	32·7
AGROPYRON SMITHII....................	1·19	1·28	1·52	68·4	22·2
KOELERIA CRISTATA......................	0·72	0·97	0·70	31·5	10·2
POA SECUNDA............................	0·36	0·60	0·22	9·9	3·2
CAREX FILIFOLIA.........................	0·23	0·80	0·18	8·1	2·6
EUROTIA LANATA.........................	0·33	1·48	0·49	22·1	7·2
ATRIPLEX NUTTALLII....................	0·06	2·34	0·14	6·3	2·1
Total............................	9·21	....	6·83	307·5	100·0

It is evident from the figures in table 5 that the principal forage plants differed greatly both in yield per unit area occupied (column 2) and in average yield per acre on the experimental pastures (column 4). *Bouteloua,* although first in area occupied, yielded less forage than either *Stipa* or *Agropyron.* The two dwarf shrubs, *Eurotia* and *Atriplex* produced higher yields per unit area than did any of the grass species, but were not sufficiently abundant to constitute a large part of the total forage.

All of the 8 species mentioned above were not only abundant, but also highly palatable and nutritious to live stock. Many other species were palatable also, but occurred too rarely to rank as important forages. On the other hand there were many plants, particularly forbs such as *Artemisia frigida* and *Phlox Hoodii* which were fairly abundant but which were eaten little or not at all by cattle.

FIG. 3.—Area of shallow soil in short-grass prairie dominated by *Bouteloua gracilis*. The abundance of *Opuntia polyacantha* indicates that the area has been over-grazed in the past.

FIG. 4.—Type of short-grass prairie dominated by *Stipa comata* (*speargrass*). The soil is a fairly deep sandy loam.

Plant Communities

Most of the vegetation of the experimental area belongs to the short-grass prairie association. The most abundant species in this community are *Bouteloua gracilis* and *Stipa comata.* Other dominants, in order of relative abundance are *Agropyron Smithii, Koeleria cristata, Poa secunda* and *Carex filifolia.* These six species comprise over 80 per cent of the plant cover. The principal forbs are *Artemisia frigida* and *Phlox Hoodii,* while a dwarf shrub, *Eurotia lanata* is fairly common. Other characteristic species include *Opuntia polyacantha, Sphaeralcea coccinea, Gutierrezia diversifolia* and *Atriplex Nuttallii.* An extremely dwarfed clubmoss, *Selaginella densa,* is very abundant, its basal area equalling that of all other species combined. Due to its low stature and slight moisture and nutrient requirements it was not considered as a dominant of the association, despite its great abundance.

Considerable variation in the composition of the short-grass prairie association occurs as a result of local differences in soil and topography. The principal sub-type produced by these factors is the *Agropyron* consociation. This community occurs on alluvial flats where soil moisture conditions are usually more favourable than on the uplands, but where the content of nitrogen and available phosphorus in the soil is low (table 2). The sole dominant is *Agropyron Smithii,* which often forms nearly pure stands. Less common grass species include *Koeleria cristata* and *Poa secunda,* while the principal forbs are *Gutierrezia diversifolia* and *Phlox Hoodii. Bouteloua gracilis* and particularly *Stipa comata* are rare or lacking in this plant type.

On the uplands the proportions of *Bouteloua* and *Stipa* vary considerably. On areas of shallow or eroded soil, or on dry, exposed slopes *Bouteloua* is often clearly dominant (Fig. 3), with *Agropyron Smithii* and *Poa secunda* next in importance. *Stipa* dominates on areas of deeper soil and slightly better moisture conditions (Fig. 4). *Koeleria cristata* is frequently associated with *Stipa* as a second dominant.

Some idea of the relative extent of the areas dominated mainly by each of the three principal species may be formed from the data supplied by 475 permanent metre quadrats distributed over the Station pastures. Fifty-two per cent of these plots were dominated mainly by *Bouteloua gracilis,* 25 per cent by *Stipa comata* and 21 per cent by *Agropyron Smithii.* Only 2 per cent were dominated by either *Koeleria cristata* or *Poa secunda.* The degree of dominance exerted by the principal species on the uplands is not usually so great as that found on the alluvial flats. In the former areas a number of species usually occur in considerable abundance, while on the latter *Agropyron Smithii* often forms nearly the entire plant cover.

The productivity of areas dominated by each of the three principal species was studied over a period of 6 years by means of clipped plots. The average yields obtained in pounds per acre of air dry forage were as follows: *Bouteloua* plots—160 pounds, *Stipa* plots—280 pounds, and *Agropyron* plots—340 pounds. These figures are not entirely in accord with those obtained in studies of the yielding ability of individual species. The reason for this difference is that a mixture of forage species occurred on most plots, particularly on those dominated by *Bouteloua* and *Stipa.*

While most of the experimental area is occupied by the short-grass prairie association, a number of other plant communities occur on special habitats. Most of these minor types are produced as a result of environmental factors, particularly soil moisture and salt content.

Moderately moist areas are dominated mainly by mesophytic grasses such as *Agropyron pauciflorum, Stipa viridula, Poa Canbyi* and *Muhlenbergia squarrosa.* Patches of shrubs, chiefly *Symphoricarpos occidentalis* often occur under these conditions.

On soils of high moisture content, as in wet meadows and along coulee bottoms, the principal plants include *Eleocharis palustris, Juncus ater, Carex* spp., and *Deschampsia caespitosa.*

Areas where surface soil moisture penetrates to considerable depths are often dominated by shrubs, including *Artemisia cana, Rosa Macounii* and *Symphoricarpos occidentalis. Salix interior* and other species of willow occur along the bottoms of coulees where favourable soil moisture conditions are combined with shelter from the strong winds characteristic of the region.

Moist, highly saline areas are dominated mainly by halophytic grasses, including *Distichlis stricta, Puccinellia Nuttalliana* and *Spartina gracilis.*

On badly eroded slopes where the grass cover is sparse or lacking the principal species include xerophytic forbs such as *Phlox Hoodii, Paronychia sessiliflora, Eriogonum flavum, Orophaca caespitosa, Hymenoxys Richardsonii* and *Sideranthus spinulosus.*

The vegetation of the blow-out areas is usually very sparse and consists mainly of herbaceous forms such as *Polygonum* sp., *Gutierrezia diversifolia* and *Opuntia polyacantha,* along with dwarf shrubs including *Atriplex Nuttallii* and *Eurotia lanata.* Certain grass and sedge species such as *Agropyron Smithii* and *Carex Eleocharis* which propagate mainly by means of rhizomes are common. While there is a trend towards development of typical short-grass prairie on these spots, succession appears to be very slow because of the unfavourable conditions existing for plant growth.

THE INFLUENCE OF CLIMATE UPON PLANT GROWTH AND FORAGE PRODUCTION

In view of the prime importance of climatic factors upon plant growth, it was considered essential to obtain detailed information regarding the climate of the experimental area and its relation to the nature and productivity of the plant cover. A weather station was established near the Station headquarters as soon as experimental work was initiated and additional climatic data were obtained at selected sites on the adjacent prairie. The general relationships between the climate and vegetation of the area were investigated and detailed studies were made of the effects of seasonal variations in climate upon the growth development and forage yield of the principal native plants.

General Meteorological Data

Records of precipitation, evaporation, air temperatures, humidity, wind mileage and duration of sunshine were obtained throughout the period 1929 to 1939. Summaries of the data for each of these climatic factors are presented in the following section.

The data for precipitation are presented in table 6. The records have been grouped into growth years from October 1 to September 30, rather than into calendar years. Precipitation which occured after the end of September in any season was not utilized for growth during that calendar year, and any benefit from it was obtained by the vegetation in the following spring.

The annual average precipitation was low, and marked fluctuations occurred from season to season. The most favourable feature was the type of distribution with fully half the annual total coming during the period April to July inclusive, at a time when other climatic factors were also favourable for plant growth. The worst years of drought during the period covered by these data were the seasons of 1936 and 1937 when rainfall during the spring and early summer months was much below average.

The records obtained at the Station agreed rather closely with those for the same period at the city of Medicine Hat, 90 miles to the north. The monthly and annual totals at the latter point were all slightly higher than at

TABLE 6.—MEAN MONTHLY AND ANNUAL PRECIPITATION, 1929 TO 1939 INCLUSIVE

Month	1928 –29	1929 –30	1930 –31	1931 –32	1932 –33	1933 –34	1934 –35	1935 –36	1936 –37	1937 –38	1938 –39	Average
October	0·12	1·53	0·87	0·05	0·48	0·98	0·62	0·35	0·89	0·26	0·33	0·59
November	0·00	0·46	1·20	0·75	1·52	0·65	0·24	0·42	0·30	0·58	1·15	0·66
December	0·47	1·40	0·00	0·45	0·18	1·20	0·32	0·22	1·10	0·16	1·50	0·64
January	1·05	0·60	0·20	0·20	0·20	0·25	1·20	0·70	0·87	0·42	0·88	0·60
February	0·70	0·39	0·10	0·13	0·10	0·05	0·30	0·70	0·40	1·29	0·40	0·41
March	1·12	0·60	0·51	0·38	0·23	1·19	0·30	0·55	0·95	0·98	0·66	0·68
April	2·60	2·26	0·45	1·69	1·27	0·36	1·06	0·72	0·24	0·50	0·40	1·05
May	1·33	0·65	0·50	2·25	2·61	0·46	0·91	0·64	0·31	1·66	0·56	1·08
June	1·51	2·74	2·31	2·18	1·97	3·39	0·91	1·12	2.08	2·22	2·97	2·13
July	0·34	0·45	2·56	1·55	0·01	0·38	2·33	0·15	1·17	1·92	1·16	1·09
August	0·00	0·62	0·69	1·42	1·97	0·45	0·08	1·46	0·57	0·11	0·21	0·69
September	0·72	1·68	0·78	1·36	0·69	1·86	0·14	0·16	1·45	2·59	0·65	1·10
Total	9·96	13·4	10·2	12·4	11·2	11·2	8·41	7·19	10·3	12·7	10·9	10·72
April-July Total	5·78	6·10	5·82	7·67	5·86	4·59	5·21	2·63	3·80	6·30	5·09	5·35

the former, the average annual total for the period 1929 to 1939 being 12·4 inches. The seasonal distribution of precipitation at Medicine Hat was very similar to that observed at the Station. The long-term (56-year) record at Medicine Hat, where the average annual precipitation has been only 12·7 inches, indicates the semi-arid nature of the short-grass prairie country. The periodic occurrence of severe drought periods is also evident from these records.

Losses from a standard evaporation tank were determined during the period May to September inclusive of the years 1929 to 1939. A summary of the data obtained is presented in table 7.

TABLE 7.—MONTHLY EVAPORATION FOR THE PERIOD MAY TO SEPTEMBER INCLUSIVE, 1929 TO 1939

Year	Evaporation in Inches					
	May	June	July	August	September	Total
1929	4·73	7·14	8·88	7·88	4·36	32·99
1930	5·03	7·23	9·18	8·73	3·59	33·76
1931	6·84	7·94	8·06	6·13	4·22	33·19
1932	4·65	3·58	8·90	5·76	3·67	26·56
1933	4·68	7·76	11·45	7·25	5·41	36·55
1934	8·43	5·40	8·20	8·40	2·62	33·05
1935	3·75	7·33	8·58	7·56	5·65.	32·87
1936	6·89	8·30	11·69	6·71	5·30	38·89
1937	6·50	6·73	6·57	7·02	3·61	30·43
1938	3·86	4·22	6·64	6·86	5·19	26·77
1939	6·06	5·70	10·91	9·46	6·14	38·27
Average	5·58	6·48	9·01	7·43	4·52	33·02

Monthly and seasonal totals of evaporation were relatively high, and fluctuated greatly in different years. Seasons of drought were marked generally by high rates of evaporation as well as by deficiencies of rainfall.

Mean monthly air temperatures for the period 1929 to 1939 are presented in table 8.

TABLE 8.—MEAN MONTHLY AND ANNUAL TEMPERATURES, 1929 TO 1939

Month	1929	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939	Av.
January	–0·1	–3·6	24·2	13·3	16·0	22·7	2·5	5·6	–7·3	21·0	24·9	10·8
February	3·6	25·8	30·8	15·3	11·4	26·0	16·5	–15·0	7·8	3·3	5·6	11·9
March	33·5	26·5	29·6	18·8	25·4	27·1	21·4	26·3	25·8	27·7	26·2	26·2
April	35·4	46·2	42·6	43·4	38·1	46·6	34·9	38·4	42·9	41·8	43·8	41·3
May	49·1	50·4	53·3	48·2	51·6	57·3	48·4	60·4	54·1	50·1	56·7	52·7
June	58·0	59·5	63·2	60·8	64·8	57·5	58·7	63·8	61·5	62·4	55·5	60·5
July	67·5	69·8	66·7	67·6	68·3	67·5	68·9	76·3	69·5	68·2	70·2	69·1
August	68·9	69·1	65·3	66·1	66·3	65·5	64·0	66·7	64·9	65·3	67·8	66·4
September	49·8	54·2	54·5	54·2	53·2	48·3	56·5	55·4	55·2	64·3	56·4	54·7
October	45·1	36·7	44·4	39·3	39·9	44·9	42·5	45·6	46·4	42·2	39·2	42·4
November	27·4	26·3	22·9	26·4	32·0	32·0	22·6	31·1	35·2	26·0	36·6	29·0
December	17·7	23·2	18·4	15·3	7·8	15·3	20·7	14·4	13·5	20·8	27·4	17·7
Average	38·0	40·3	43·0	39·1	39·6	42·6	38·1	39·1	39·1	41·1	42·5	40·2

The yearly range in mean monthly temperatures amounted to 58° F. Differences in mean temperatures for the same months in different years were greater in the winter than in the summer months, deviating as much as 14 degrees from the 11-year average in the former and 7 degrees in the latter season.

The average frost-free season for the period 1929 to 1939 was 124 days, ranging from a minimum of 98 days in 1930 to 140 days in 1939. The average dates of the last spring and first autumn frosts were May 17 and September 17 respectively.

High winds were of frequent occurrence during practically every month of the year. The average monthly wind mileage during the growing seasons of 1936 to 1939 inclusive was as follows: April—9,170; May—10,002; June—8,330; July—6,363; August—7,557 and September—6,975 miles. Undoubtedly this amount of wind was a factor of considerable importance with respect to rate of water loss from both vegetation and soil. Wind velocities were generally highest during the months of April, May and June at the time when plant growth was most active. The effects of high winds and low humidity were apparent in the rapid drying of the surface soil following rains.

The daily number of hours of bright sunshine was recorded during the period of study. The average daily amounts during the summer months were as follows: April—6·5, May—8·4, June—8·8, July—11·1, August—9·9 and September—6·9 hours. It did not appear that sunshine was a limiting factor particularly in view of the open structure of the native plant cover.

The Native Vegetation in Relation to Climate

The vegetation of the experimental area is composed of species well adapted for existence under the rigorous climatic conditions prevailing in the region. The dominant plants are low-growing perennial grasses with exten-

sive and finely branched root systems. Plants with more exposed perennial portions, such as trees and shrubs are confined to situations where moisture conditions are better than average. The principal non-grass forms are low-growing perennial forbs and dwarf shrubs, most of which exhibit reduced leaf surfaces, abundance of epidermal hairs and other xeromorphic features.

The annual growth cycle of the principal plants is well adapted to the seasonal conditions. Most species begin growth early in April and develop rapidly during the relatively favourable period of April, May and June. Plant development is practically completed in most cases by the first of July, before the regular mid-summer drought has begun. While some species produce a certain amount of seed in all but very dry years, abundant seed production for the majority of plants occurs only in seasons when precipitation is above normal. Vegetative propagation is common among many of the principal species.

A feature of the response of the vegetation to the climatic conditions is the annual drying or curing which occurs, particularly in the case of the grasses. When the available soil moisture becomes exhausted, as usually happens before the end of July, the vegetation becomes cured, and usually remains in that condition for the remainder of the year.

This curing of the native grasses is one of the principal factors which make the region so well adapted for range live-stock production. The dried plants remain erect and available for grazing for many months after drying while their nutritive value is generally adequate for the maintenance of range live stock in good condition.

The principal exception to the common growth cycle occurs in the development of *Bouteloua gracilis.* This species begins growth nearly a month later than do the other dominant grasses and continues to grow slowly for several weeks after the latter have become relatively inactive. *Bouteloua* exhibits to a marked degree the ability to withstand periods of drought during the growing season and to resume growth quickly whenever soil moisture becomes available. Because of its late period of development, seed production in this species is confined mainly to years when precipitation during July and August is above normal.

Effect of Climatic Factors on Seasonal Plant Growth

A detailed study of the seasonal growth development of the dominant grasses and of the effects of different climatic factors upon this growth was made during the period 1934 to 1939 inclusive. Two sites were established on representative areas of native vegetation close to the Station headquarters. One site was on upland prairie dominated by *Bouteloua* and *Stipa,* while the other was on an alluvial flat occupied mainly by *Agropyron Smithii.* The species studied included *Bouteloua gracilis, Stipa comata, Koeleria cristata* and *Poa secunda* on the upland area and *Agropyron Smithii* on the flat. Each season about 20 individual plants of each of these species were marked, and their growth development studied at weekly intervals. Date of first growth, weekly rate of growth, time of culm production, flowering, etc., were determined for each plant separately and the results averaged for each species.

Records of evaporation, soil temperature and soil moisture were obtained at these same sites. Data on precipitation and air temperatures were taken from the records of the regular weather station which was located close to the two sites. Evaporation was measured at the sites by means of Livingston white spherical atmometers placed with the bulbs about 10 inches above the ground. Soil temperatures were determined by means of mercury thermometers inserted to the desired depths and read several times daily. Soil moisture samples were taken at weekly intervals from a depth of 1 to 6 inches, and from greater depths at less frequent intervals.

The weekly measurements of growth afforded a fairly detailed picture of the development of the five species being studied. Growth began in early spring for four of the five, the average dates being as follows: *Koeleria* and *Poa*—April 2, *Agropyron*—April 7, and *Stipa*—April 8. *Bouteloua gracilis* did not begin growth until a month later, the average date being May 3. Growth of the four earlier species proceeded rapidly during the spring months, the period of maximum leaf growth occurring during the first half of May in most cases. *Koeleria* and *Stipa* made practically no growth after the middle of July, while *Poa secunda* usually became inactive in late June. *Agropyron* continued growth until nearly the end of July and *Bouteloua* grew slowly until the middle of August on an average.

Soil temperatures at the 6-inch depth on the upland station averaged 40° Fahrenheit at the beginning of April and rose steadily to a weekly average of 77 degrees by the middle of July. After that date there was a gradual decline. Temperatures at site 2 in clay loam soil averaged one degree lower than at the upland site during the period April to July.

The amount of available soil moisture was higher at the lowland site, averaging 6 per cent above that found in the sandy loam soil of the upland station. Soil moisture was usually exhausted on the latter area by July 15, and on the former by the end of July.

Evaporation from the atmometers fluctuated considerably in response to variations in temperature, humidity and wind, but the general course was upward from an average weekly loss of 271 ccs. in late April to 578 ccs. per week in mid-July. There was no appreciable difference in rate of loss between the two sites.

Comparisons of growth of the different species during the six seasons of the study with climatic records obtained during this same period from the two sites indicated that two climatic factors were of direct importance in seasonal plant growth. These were temperature in early spring, and available soil moisture during the remainder of the growing season. There was a fairly close relationship between soil and air temperatures and the date of first growth for the different species. *Stipa comata* began growth each year when the 6-inch soil temperature approached a daily average of 42° F. Mean daily air temperature at this time averaged 40° F. *Agropyron, Koeleria* and *Poa* all started at slightly lower temperatures. *Bouteloua* on the other hand, did not begin to grow until the 6-inch soil temperature averaged 52° F., which condition was usually reached about a month later. There was a fairly close association between rising soil temperatures and increased growth rate for the four earlier species from the time that growth began until the end of April. At that time the weekly soil temperature at the 6-inch depth averaged 52° F.

After the end of April, there was little apparent relationship between soil temperatures and rate of growth, and available soil moisture became the most important factor. The curves of growth and soil moisture followed each other fairly closely during May and June, and the end of the period of active growth coincided with the date when available soil moisture became exhausted. This occurred on an average at the middle of July on the upland station and at the end of that month on the *Agropyron* site.

The relation of the growth of *Agropyron Smithii* to the factors of soil temperature and available soil moisture is presented graphically in Fig. 5.

During most years, temperatures remained suitable for growth until some time in October, but due to the lack of soil moisture little active growth of the major species occurred after the end of July, and most of the vegetation cured in July or August. Some fall growth, particularly of *Poa, Koeleria* and *Agropyron* occurred in years of heavy September rainfall, but on the whole plant activity in this season was very limited.

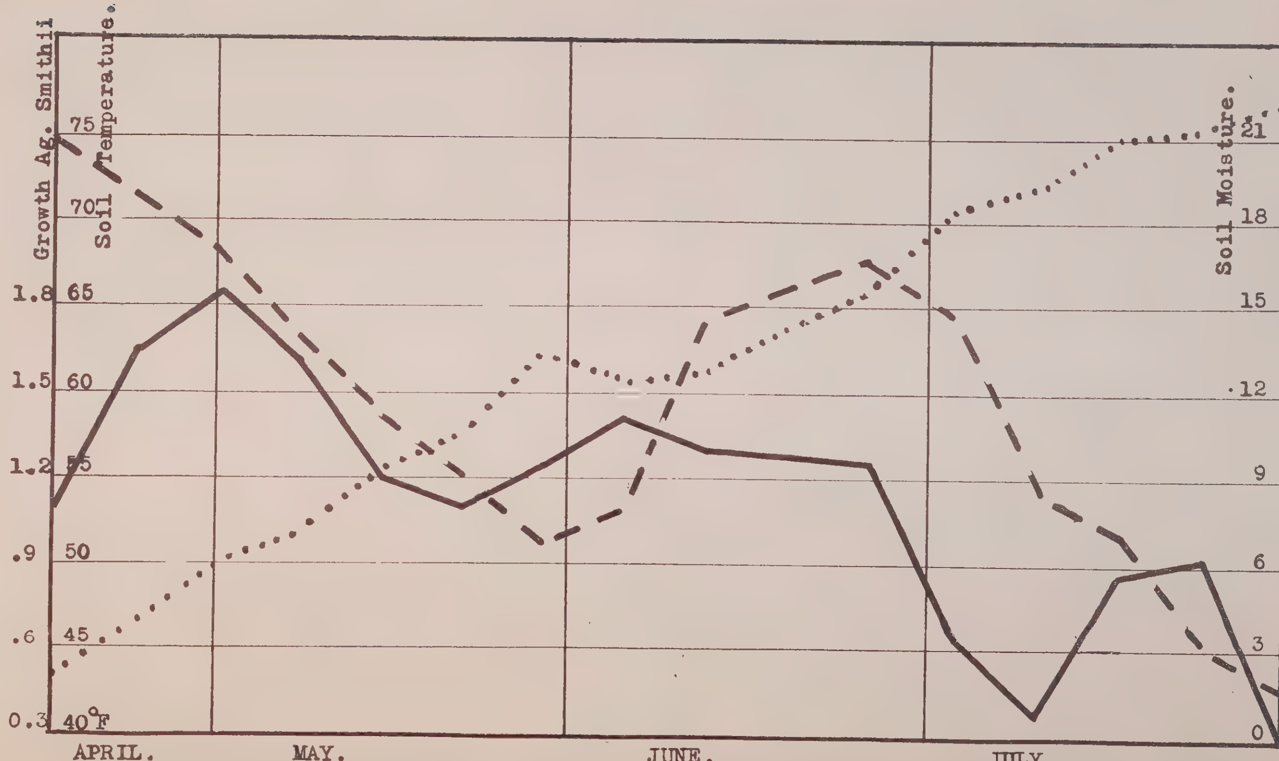

FIG. 5.—Relation between weekly growth rate of *Agropyron Smithii* in cms. (solid line), average weekly soil temperature at 6 inches (dotted line) and available soil moisture in per cent (broken line) for the period April 15 to July 31. All data represent averages for the 6-year period 1934 to 1939 inclusive.

Effects of Climate on Forage Production

While the effects of climate upon the seasonal period and rate of plant growth are of considerable importance in relation to grazing, the carrying capacity of a pasture is determined mainly by its annual production of forage. In order to study the effects of climatic factors on forage production, a number of plots were established on protected areas in the Station pastures. Thirty-six of these plots, each four square yards in area and located on representative areas in the main plant associations, were clipped annually and their forage yield determined. The vegetation was harvested by means of hand clippers. Since the plots were clipped only once each year after the vegetation was mature, productiveness was not impaired, and the annual yields could be considered as being influenced primarily by seasonal climatic conditions.

TABLE 9.—AVERAGE ANNUAL FORAGE YIELD COMPARED TO PRECIPITATION, EVAPORATION, AND THE P/E RATIO FOR THE SEASONS OF 1931-1939

	1931	1932	1933	1934	1935	1936	1937	1938	1939	Average
Forage Yield (lb. per acre).......	250	365	263	220	290	163	250	387	312	279
Precipitation (April to July)......	5·82	7·67	5·86	4·59	5·21	2·63	3·80	6·30	5·09	5·22
Evaporation (May to July).......	22·8	17·1	23·9	22·0	19·7	26·9	19·8	14·7	22·7	21·1
Ratio of Precipitation to Evaporation.........................	0·26	0·45	0·25	0·21	0·26	0·10	0·19	0·43	0·22	0·26

The data obtained from individual growth measurements and studies of climatic factors at the two growth sites mentioned previously indicated that moisture conditions were of prime importance in limiting plant growth. Efforts

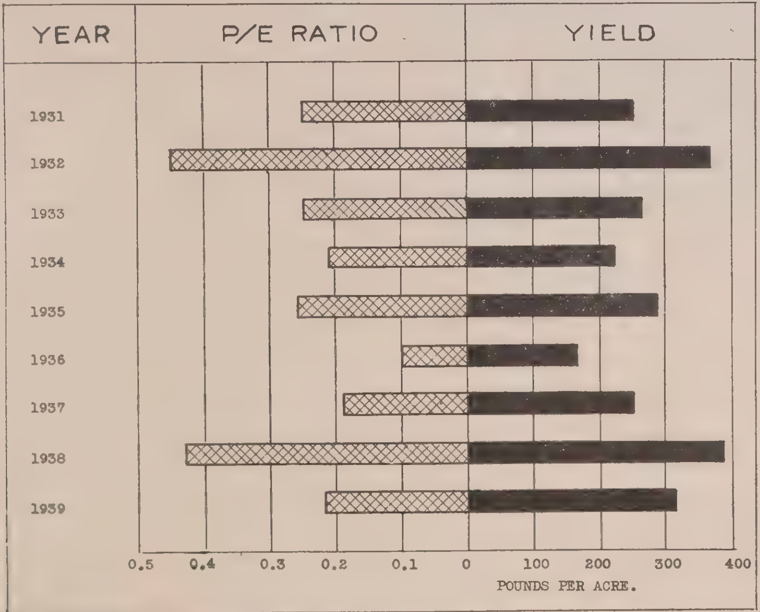

Fig. 6.—Relation of annual forage yield of short-grass prairie vegetation to ratio of precipitation to evaporation during the main growth period. (April to July inclusive.)

to relate annual fluctuations in forage production to climatic factors led to the establishment of a fairly close relationship with the precipitation evaporation ratio for the growing season. Probably soil moisture data would have given even closer agreement with forage yields, but such information was not available for the clipped plots. The figures obtained for forage yield, precipitation, evaporation and the P/E ratio during the period 1931 to 1939 are presented in table 9. The rather close relationship between these factors is shown graphically in Fig. 6.

Forage production varied greatly in different years, ranging from 387 pounds per acre in 1938 to 163 pounds in 1936. Evidently yields were influenced mainly by moisture conditions, particularly as reflected in the P/E ratio. Moisture from rains of the previous fall or from winter snow did not appear to be nearly so important as precipitation during the growing season.

Data on the relative productivity of the three main forage species during different parts of the growing season were obtained by means of clipped plots. On sites dominated by each of these three grasses, namely *Bouteloua gracilis, Stipa comata* and *Agropyron Smithii*, one set of plots was clipped at the end of May, another at the end of June and still another group at the end of July. Taking the yield obtained at the end of July as the maximum, the yields from the earlier clippings were calculated in percentages of this total. The data obtained in this way are presented in table 10.

TABLE 10.—PERCENTAGE YIELD PRODUCED BY DIFFERENT FORAGE SPECIES CLIPPED AT VARIOUS INTERVALS DURING THE SEASONS OF 1934-1939

Interval	Yield of Dominant Species in Per Cent		
	Bouteloua gracilis	Stipa comata	Agropyron Smithii
April and May	35	51	50
June 1 to July 1	47	39	40
July 1 to August 1	18	10	10
Total Yield	100	100	100

Areas dominated by *Stipa* and *Agropyron* agreed closely in percentage of forage produced in the different parts of the growing season. Plots occupied chiefly by *Bouteloua* produced a much lower percentage of their total yield in April and May. This was due to the fact that *Bouteloua* began growth about a month later than did *Stipa* or *Agropyron* and grew more slowly after it did start.

Significance of Climatic Conditions and Plant Growth in Relation to Grazing

The close relationship existing between certain climatic factors and plant development, together with the occurrence of marked annual fluctuations in both climate and plant growth are factors of great importance in relation to grazing on short-grass prairie ranges. It is evident from the data presented that the quantity, quality and availability of the native forage is affected greatly by climatic conditions. The average yield of forage is low, as might be expected in view of the low precipitation and high evaporation rate. The effect of climate on the quality of the herbage is evident in relation to the curing of the vegetation on completion of the relatively short period of seasonal development. The forage retains much of its nutritive value after becom-

ing cured, and subsequent losses by weathering are slight due to the dry climatic conditions. The cured vegetation tends to remain fairly erect and available for grazing until well into the following growth season. In winter the amount of snowfall is usually light, and the chinook winds aid in keeping the ground free from a heavy snow covering which would interfere with grazing.

The marked annual fluctuations which occur in both climatic factors and plant growth are of particular importance in affecting grazing capacity. It is evident that in establishing a safe rate of grazing for any unit of range, allowance must be made for the occurrence of seasons when production may be as low as 60 per cent or less of the long-term average. On the other hand, the rate of grazing should be such as to provide for a fairly heavy carryover of forage in years when conditions for plant growth are better than average.

THE EFFECTS OF DIFFERENT INTENSITIES OF GRAZING UPON THE VEGETATION

A study of the effects of different intensities of grazing was conducted on the Station pastures during the period 1932 to 1938. The rates of stocking tested were 20, 30 and 40 acres per head for an annual grazing season of approximately 7 months (April to October inclusive). Ten head of cattle were used in each of the three fields which were respectively 200, 300 and 400 acres in size. The areas chosen for the three pastures were highly comparable with regard to vegetation, topography, watering facilities, etc.

The cattle used in the test were good quality Herefords, selected for uniformity. The experiment was begun in 1932 with 30 head of yearling heifers, and these same animals were used in the same fields throughout the duration of the test. The heifers were bred as 2-year olds, and in each of the following years, so that there were calves as well as cows in the fields from 1934 to 1938.

The effects of grazing on the plant cover were studied mainly by means of quadrats, exclosures and systematic utilization surveys. Two series of metre quadrats were established in 1931; one set by the area list method and the other by the pantograph chart method. The area list plots were studied again in 1933 and 1937, the pantograph quadrats in 1935 and 1939. Thus the final study of the area list quadrats was made one year before the end of the test and that of the pantograph plots was made a year after the end of the experiment.

Results of Quadrat Studies

Considerable information regarding the changes which occurred in the vegetation at the three rates of grazing was obtained from study of the list quadrats. There were 85 of these plots altogether in the three fields. The data were compiled and analysed statistically in order to determine where significant changes had occurred. As might be expected with native vegetation there was great variability between the plant cover of different quadrats even within the same community. The method used in the analyses was that of paired plots with the data from a single quadrat at two different dates of charting constituting a pair. A summary of the data obtained from the area list quadrats is presented in table 11.

The response of the two principal grass species to the three intensities of grazing was very different. The area occupied by *Bouteloua* did not change significantly on any of the three fields although the decrease on the pasture grazed at the 40-acre rate was close to the point of significance. The area occupied by *Stipa* decreased at the 20- and 30-acre rates of grazing, but did not change at the 40-acre rate. This difference in response was indicated also by

the trend of the ratio of *Bouteloua* to *Stipa*. This ratio declined significantly (by 31 per cent) at the 40-acre rate and did not change at the other two intensities of grazing. Both *Koeleria* and *Poa* increased on all three fields, the latter in direct proportion to the intensity of grazing.

The principal forb, *Artemisia frigida* decreased on all three fields, but the decrease was least on the pasture grazed most heavily. *Phlox Hoodii*, a low-growing forb which did not compete to any great extent with the grasses increased at the 40-acre rate of grazing but not at the two heavier intensities. *Selaginella* increased on all three fields with the greatest gain occurring on the lightly grazed area.

TABLE 11.—CHANGES IN BASAL AREA OF MAIN SPECIES AT DIFFERENT INTENSITIES OF GRAZING

Name of Species	Basal Area Occupied (in per cent)								
	40 acre rate			30 acre rate			20 acre rate		
	1931	1937	Diff. %	1931	1937	Diff. %	1931	1937	Diff. %
Bouteloua gracilis..........	3·87	2·74	−29	3·37	2·80	−17	3·77	2·96	−21
Stipa comata..............	1·97	2·01	+ 2	1·79	1·41	−21	2·62	1·86	−27
Agropyron Smithii........	0·74	0·77	+ 4	1·22	1·25	+ 2	0·86	0·78	− 9
Koeleria cristata..........	0·36	0·69	+92	0·43	0·69	+60	0·50	0·90	+80
Poa secunda...............	0·14	0·41	+192	0·10	0·64	+540	0·05	0·54	+980
Other Grasses and Sedges	0·61	0·92	+51	0·75	0·84	+12	0·06	0·16	+167
Total............	7·69	7·54	− 2	7·66	7·63	−0·4	7·86	7·20	−8·5
Artemisia frigida..........	0·46	0·16	−65	0·72	0·22	−69	0·62	0·41	−34
Phlox Hoodii..............	0·48	0·98	+104	0·49	0·61	+24	0·78	0·70	−10
Selaginella densa.........	11·0	20·9	+90	12·0	18·0	+50	15·0	20·0	+33

NOTE—Statistical significance of changes is indicated by underlining of figure for percentage difference. Single underlining indicates moderately significant differences (odds of 19:1 or greater), while double underscoring indicates high significance (odds of 99:1 or greater).

The pantograph chart quadrats were much fewer in number than those studied by the area list method, there being only 38 of the former altogether on the three fields. These plots were of considerable importance, however, since they were recharted for the last time in 1939 and thus covered the period of the experiment a little more fully than did the area list quadrats. Most of the changes in plant cover shown by the data from the two sets of quadrats were similar. The principal features were the decline of *Stipa comata* at the two heavier rates of grazing and the great increase in area occupied by *Poa secunda* in all three fields. Differences between the two series of quadrats concerned changes in area occupied by several species as well as changes in forage yield indices. According to the pantograph chart data, *Koeleria* decreased in area in the field grazed at 20 acres per head, while no significant change occurred in the other two pastures. *Artemisia frigida* decreased at the 40-acre rate of grazing, but increased at the two heavier intensities towards the end of the test. *Phlox Hoodii* increased on all three fields.

The changes in forage yield indices were much more marked on the pantograph chart quadrats than on the area list plots. On the former there was no change for the field grazed at 40 acres per head, but decreases of 20 and

34 per cent were recorded for the pastures grazed at the two heavier rates, while on the latter there were no statistically significant changes at any of the three intensities of grazing.

Data obtained from studies of the quadrats in the intermediate years of the experiment indicated that the trends of vegetational change varied considerably. On the area list plots there was an increase in basal area of practically all species during the period 1931 to 1933, and a subsequent decline. This early increase represented the response of the vegetation to the relatively favourable seasons of 1932 and 1933, together with the rather light intensity of grazing due to the fact that the fields were occupied by heifers which would not consume as much forage as would cows and calves. The general decline in plant cover which occurred during the period 1933 to 1937 appeared to be due to the combined effects of unfavourable climatic conditions and heavier grazing (by cows and calves).

The data from the pantograph chart quadrats did not show this early increase to any marked extent, since dry seasons occurred prior to the first recharting which was done in 1935.

Significance of the Quadrat Data in Relation to Grazing Intensity

While the duration of the experiment was too short to bring out fully the effects of different grazing intensities on the plant cover, certain definite trends were evident in the data obtained from the two series of quadrats.

The data indicated that the three fields were highly comparable in their plant cover. The total grass covers, proportions of the various forage species and average forage yield indices for the pastures were all quite similar. Hence differences in response of the plant cover during the period of the experiment were attributable to the grazing practices tested rather than to any inherent inequality in the vegetation of the fields.

In the field grazed lightly (40 acres per head), the principal change was the decline in basal area of *Bouteloua gracilis*, the main short-grass species of the area. The cover of *Stipa*, *Agropyron*, *Koeleria* and other mid-grasses remained practically unchanged. This shift in the proportion of short to mid-grasses was indicated by the significant decrease which occurred in the ratio of *Bouteloua* to *Stipa*. Evidently the mid-grasses were favoured in competition with the short grasses by a light rate of grazing. The principal weed species, *Artemisia frigida* declined during the period of study. The potential productivity of the field, as measured by the average forage yield index of all quadrats, declined only slightly during the period, and this decline appeared directly attributable to drought rather than to the effects of grazing. Quadrats on areas protected from grazing showed a similar decrease in yield index during the same period.

On the field grazed at the rate of 20 acres per head there was a decrease in total grass cover, due mainly to a decline in basal area of both *Bouteloua* and *Stipa*. The latter species decreased more than the former, as indicated by an increase in the *Bouteloua:Stipa* ratio. Evidently heavy grazing favoured *Bouteloua* in competition with *Stipa* and other mid-grasses. These data are in agreement with the results obtained by Sarvis (9, 10) who found that *Stipa* decreased much more than did *Bouteloua* under heavy grazing at Mandan, North Dakota.

The cover of *Artemisia frigida* decreased until 1937 and then increased rapidly. This sudden increase appeared to be due mainly to the occurrence of relatively favourable climatic conditions in 1938 and 1939 at a time when the grass cover was in a depleted condition resulting from the combined effects of close grazing and drought. The forage yield index for this pasture declined significantly, most of the decrease coming at the end of the test period.

The response of the field grazed at 30 acres per head was intermediate between that of the other two pastures. The decrease in area occupied by *Stipa* was less than on the field grazed at 20 acres per head, while there was no significant change in the ratio of *Bouteloua* to *Stipa*. Potential productivity, as measured by the forage yield index, remained practically unchanged until 1937 and then declined slightly.

Fig. 7.—Fields grazed at rates of 20 acres per head (top photo) and 40 acres per head (bottom photo). Photos taken during the grazing season of 1936, a very dry year. Note closely grazed conditions of both grass and sagebrush in upper figure.

Utilization Studies

Surveys were made of each pasture annually to determine the degree of forage use under different intensities of grazing. The extent of utilization was found by estimating the amount of available forage left on each field at the end

of the grazing period. These amounts were compared with the total available forage present on comparable ungrazed areas. The technique used involved making visual estimates at fixed distances along numerous transects in each field. Available forage was considered as that portion of the total season's growth which would normally be grazed by cattle, since this was the type of live stock used in the experimental work. The amount of forage carryover on grazed fields was expressed as percentages of the total present on protected areas. While results of high accuracy could not be expected from such a method, the data obtained for the different fields were comparable and afforded an approximate measure of forage utilization without requiring an undue amount of time and effort.

The results of these studies indicated that the average carryover of forage on the fields grazed at 40 and 30 acres per head was adequate, being nearly 35 per cent for the latter pasture and somewhat higher for the former. The average carryover on the field grazed at 20 acres per head was insufficient, being slightly over 20 per cent. Probably more important than the average carryover was the amount in the drier years. At the 20-acre rate of grazing there was practically no forage left at the end of the grazing season in 1936 or 1937.

The carryover during these same years was 22 per cent on the field grazed at 40 acres per head and 15 per cent at the 30-acre rate of grazing. To sum up, the carryover on the field grazed at the rate of 20 acres per head was inadequate in five out of seven years, while on the other two fields there was a sufficient amount of forage left at the end of the grazing season in all but the two worst years of drought.

Response of Cattle to the Different Intensities of Grazing

The cattle used in the experiment were weighed individually at regular intervals during each season, and the weights of the calves were obtained at the time of weaning. A summary of the gains made by cattle in the different fields and of the weaning weights of their calves is presented in table 12.

TABLE 12.—AVERAGE GAINS IN WEIGHT OF CATTLE AT DIFFERENT RATES OF GRAZING

Grazing Intensity	Average Gain in weight of Cows, Weaning Wt. of Calves							
	——	1932	1933	1934	1935	1936	1937	Average
40 acres per head	Cows	322	307	198	209	247	172	242·5
	Calves	......	......	411	420	366	418	404
30 acres per head	Cows	334	307	120	159	176	102	199·5
	Calves	......	......	405	425	359	390	395
20 acres per head	Cows	319	284	136	141	22	45	158
	Calves	......	......	339	389	322	363	353

Minimum significant differences in average gain for the various lots of cows are as follows: 35 pounds between the 40 and 30 acre groups; 79 pounds between the 40 and 20 acre lots; and 57 pounds between the 30 and 20 acre lots; corresponding figures for the lots of calves are 26 pounds between both the 40 and 20, and 30 and 20 acre groups; 21 pounds between the 40 and 30 acre lots.

The average seasonal gain for the cows grazed at a rate of 40 acres per head was significantly higher than that made at the 20- and 30-acre rates of use. The difference between the lots grazed at 30 and 20 acres fell short of significance. Probably more important than differences in average gains were the trends of gain during the 6-year period and the marked differences in gains made

during the drought years. Due to the relatively good condition of the pastures at the start of the experiment, and to the lighter rate of grazing with young heifers, the gains made by the three lots did not differ greatly during the first two years of the test. As the different rates of grazing began to affect the forage cover of the pastures and the intensity of grazing was increased by the change from heifers to cows with calves, the differences in gains became increasingly marked. Under drought conditions in 1936 and 1937 the cattle on the field grazed at 20 acres per head made practically no gains during the grazing season and went into the winter in poor condition. Much more feed was required to winter these animals than was needed for the cows from the other two pastures.

It is evident that the results of a test of this nature must be evaluated on the basis of all available data regarding the effects on both plant cover and live stock with due regard for the influence of climate as well as of the grazing intensities tested.

Fig. 8.—Typical cow from field grazed at a rate of 20 acres per head (top photo) and 40 acres per head (lower figure). These photos were taken at the close of the grazing season of 1936, a very dry year.

Taking all these factors into account, it appears that the field grazed at 20 acres per head was definitely overstocked. Deterioration of the plant cover occurred, including a decline in density of forage species and an increase in unpalatable weeds. In five out of seven years the carryover of forage fell below the required level, and in the two worst drought years there was practically none. Gains made by the cows and the weaning weights of the calves were lower than on the other two pastures, while the growth development of the cows was stunted. During several winters these cattle had to receive more feed than did those from the other two fields. Altogether, there were signs of a cumulative deterioration in both vegetation and cattle which presumably would have become still more evident had the experiment been continued for a longer period.

On the pasture grazed at the rate of 40 acres per head the results were quite different. The decline in plant cover was slight and was attributable to drought rather than to grazing. There was no significant change in the forage-producing ability of the vegetation, and most weed species decreased. The average carryover of forage was adequate, and the amount fell below 25 per cent only during the two worst years of drought. The gains made by the cows, as well as the weaning weights of the calves were significantly higher than those obtained from the animals in the field grazed at the 20-acre rate. Growth development of the cows was good, and they required very little extra feeding in winter.

Results on the field grazed at 30 acres per head were in general intermediate between those obtained on the other two pastures. There was some decrease in grass cover and an increase in certain weed species, but these tendencies were not very marked, and there were indications of considerable recovery in the more favourable years following the drought period. The carryover of forage was adequate in all except the two worst years of drought. The average gains of the cows in this pasture were less than in the field grazed at the rate of 40 acres but there was no significant difference in the weaning weight of the calves in the two lots.

In view of the available evidence, it appeared that the grazing capacity of the type of plant cover contained in the three pastures was between 30 and 40 acres per head for a 7-month grazing period under the climatic conditions existing during the experiment. Climatic data for the Station and other points in the region indicated that conditions for plant growth were generally below normal during the period 1930 to 1939, and that the drought conditions of 1936 and 1937 were of a severity seldom equalled. Considering that the field grazed at the rate of 30 acres per head showed no signs of serious depletion even under such unfavourable climatic conditions, it would seem that the long-term grazing capacity of the type of vegetation studied would be closer to 30 than to 40 acres per head for a 7-month grazing season.

THE COMBINED EFFECTS OF CLIMATE AND GRAZING UPON THE NATIVE VEGETATION

During tthe period 1928 to 1939 the effect of grazing and climate upon the vegetation of the Station lands was studied by means of a considerable number of permanent metre quadrats. The majority of these were located on the various grazed pastures, while the remainder were established in fenced exclosures which were protected from grazing. Two main series of quadrats were charted, one in 1928 and the other in 1929. The former set were recharted in 1931, 1935 and 1938, while the latter were studied again in 1932, 1936 and 1939. In addition, a series of list quadrats was established in 1930 and 1931 while additional pantograph chart plots were laid out in 1932.

The presence of a considerable number of permanent quadrats charted both at the beginning and the end of the study period proved particularly valuable in view of the climatic conditions which prevailed during those years (1928 to 1939). Following a relatively favourable series of seasons from 1927 to 1929, there occurred a prolonged period of drought which was broken only slightly by the more favourable conditions which prevailed during 1932 and 1938. The seasons of 1936 and 1937 marked the culmination of the drought, and were two of the driest years to occur in southern Alberta in the 55 years during which climatic records have been obtained. Such severe climatic conditions might well be expected to mask the effects of various grazing practices on the plant cover.

In an effort to determine the relative effects of climate and grazing use upon the vegetation of the experimental area, the data from quadrats located inside fenced exclosures and on the grazed pastures were analysed and compared. The data for grazed fields were obtained from quadrats on four pastures of about 3,800 acres each which were grazed at the very moderate rate of 40 acres per head for a 7-month grazing season.

In each case the results for the *Stipa-Bouteloua* and *Agropyron* communities were treated separately.

Results of Quadrat Studies on Ungrazed Vegetation

A summary of data obtained from 24 quadrats established on *Bouteloua-Stipa* (upland) vegetation in 1929 and re-charted in 1932, 1936 and 1939 is presented in table 13.

TABLE 13.—AVERAGE DENSITY OF PRINCIPAL SPECIES IN QUADRATS ON UNGRAZED UPLAND VEGETATION, 1929-1939

Species	Basal Area Occupied (p.c.)				Percentage Change (1929-1939)
	1929	1932	1936	1939	
Bouteloua gracilis	16·03	13·51	12·10	7·10	−56
Stipa comata	7·20	6·02	5·50	3·90	−46
Agropyron Smithii	1·81	1·60	0·80	1·04	−43
Koeleria cristata	0·91	2·30	2·15	1·44	+58
Poa secunda	0·10	0·32	0·87	0·64	+540
Total Grass Cover	26·05	23·75	21·42	14·12	−46
Eurotia lanata	0·59	0·71	1·21	0·99	+68
Atriplex Nuttallii	0·29	0·20	0·26	0·43	+48
Artemisia frigida	2·07	0·90	0·21	0·90	−57

NOTE—Statistical significance of differences is indicated by underlining of figure for percentage difference. Single underscoring indicates moderately significant differences (odds of 19:1 or greater, while double underlining indicates high significance (odds of 99:1 or greater).

The most striking changes in plant cover were the decline in basal area of the two dominent grasses and the marked increase in the area occupied by *Poa secunda* and *Eurotia lanata*. The ratio of *Bouteloua* to *Stipa* did not change significantly.

Data from 14 quadrats charted in 1928 and studied again in 1931, 1935 and 1938 were in general agreement with the figures for the 1929 to 1939 series. The

only differences of any account between the two sets of quadrats were in connection with the response of *Stipa comata* and *Artemisia frigida*. *Stipa* decreased a little less and *Artemisia frigida* considerably more in the 1928 series than in the plots established in 1929. *Selaginella densa*, the dwarf prairie clubmoss, increased in basal area from approximately 11 per cent in 1931 to 16 per cent in 1938.

Data from both series of quadrats revealed the fact that marked fluctuations in the basal area occupied by various species occurred during the period of the experiment. *Bouteloua* and *Stipa* decreased mainly during the early and late years of the study, and least during the interval of 1932 to 1936. On the other hand, *Agropyron* decreased mainly during the middle period. *Koeleria* increased during the period 1929 to 1932, but declined somewhat from 1936 to 1939. *Artemisia frigida* declined greatly during the first two-thirds of the study period, and reached a very low level during the drought years of 1936 and 1937. A rapid recovery by this species began in 1938 and became marked in 1939.

Changes in numbers of plants of the various species agreed only in part with those recorded for basal area. *Koeleria*, *Poa secunda* and *Eurotia* all increased in numbers of plants as well as in area occupied. The number of plants of *Stipa* remained practically unchanged throughout the period of the experiment, despite the fact that significant decreases in basal area occurred. This apparent anomaly seemed due to the fact that the decline in density was caused mainly by a decrease in the size of clumps rather than by the death of many plants. In the case of *Artemisia frigida*, changes in numbers of plants paralleled those in area occupied, there being a marked decline during the first two-thirds of the period of the study, and a sharp increase during 1938 and 1939.

Data obtained from 18 quadrats established on ungrazed vegetation belonging to the *Agropyron* consociation are included in table 14.

TABLE 14.—AVERAGE BASAL AREA OCCUPIED BY PRINCIPAL SPECIES IN QUADRATS ON UNGRAZED VEGETATION OF THE AGROPYRON TYPE

Species	Basal Area Occupied (p.c.)				Percentage Change (1929-1939)
	1929	1932	1936	1939	
Agropyron Smithii	7·60	5·40	6·60	5·53	<u>−27</u>
Koeleria cristata	0·32	0·36	0·25	0·21	−34
Poa secunda	0·25	0·98	0·62	0·41	<u>+64</u> (double underlined)
Total Grass Cover	8·17	6·74	7·47	6·15	<u>−25</u>
Artemisia frigida	0·37	0·31	0·10	0·27	−27
Gutierrezia diversifolia	0·27	0·02	0·02	0·37	+37

NOTE. Statistical significance of differences is indicated by underlining of figures for percentage difference. Single underscoring indicates moderately significant differences (odds of 19:1 or greater) while double underlining indicates high significance (odds of 99:1 or greater).

In general, the changes in plant cover were not so marked as on the upland quadrats. *Agropyron*, the dominant species, decreased in area during the first few years of the study period, and after that remained practically unchanged in spite of severe drought conditions. *Koeleria* decreased and *Poa* increased, but the gains made by the latter were far less than on the upland quadrats. *Artemisia frigida* decreased during the drought years and then increased at the

close of the study period. The greater stability of the *Agropyron* community appeared to be connected with the fact that soil moisture conditions were usually more favourable on the alluvial flats occupied by this type than on the upland areas. This supposition is supported by data obtained in the studies reported in the section on Climate and Plant Growth.

Results of Quadrat Studies on Grazed Vegetation

A summary of data obtained from 40 pantograph chart quadrats of the 1929 to 1939 series established on upland vegetation is presented in table 15.

TABLE 15.—AVERAGE BASAL AREA OCCUPIED BY PRINCIPAL SPECIES IN QUADRATS ON GRAZED UPLAND VEGETATION, 1929-39.

Species	Basal Area Occupied (p.c.)				Percentage Change (1929-1939)
	1929	1932	1936	1939	
Bouteloua gracilis	14·97	13·26	10·75	9·48	−37
Stipa comata	8·39	6·37	3·42	3·01	−64
Agropyron Smithii	0·90	0·82	0·62	0·49	−46
Koeleria cristata	0·85	1·81	1·03	0·78	− 8
Poa secunda	0·22	1·09	1·31	1·44	+555
Total Grass Cover	25·33	23·35	17·13	15·20	−40
Eurotia lanata	0·53	0·49	0·57	0·66	+25
Atriplex Nuttallii	0·05	0·08	0·14	0·09	+80
Artemisia frigida	1·66	1·26	1·20	1·82	+10
Phlox Hoodii	0·17	0·33	0·26	0·31	+82

NOTE—Statistical significance of differences is indicated by underlining of figure for percentage difference. Single underscoring indicates moderately significant differences (odds of 19:1 or greater) while double underlining indicates high significance (odds of 99:1 or greater).

The most important changes recorded were the significant decreases in basal area occupied by *Bouteloua, Stipa* and *Agropyron,* along with the marked increase in density of *Poa secunda.*

Data were obtained also from 160 quadrats of the 1928 to 1938 series. The results from these plots were in substantial agreement with those from the 1929 to 1939 series, and any differences were in intensity rather than direction of change. The decreases in basal area occupied by *Bouteloua, Stipa* and *Agropyron* were all slightly less in the 1928 series of quadrats than in the 1929 set, while *Eurotia* increased more in the former than in the latter. As on the ungrazed quadrats, *Artemisia frigida* declined much more in the 1928 series than in the 1929 group, this being due mainly to the rapid recovery made by this species in 1938 and 1939.

Fluctuations in the density of the principal species during the period of the experiment were evident in the data from both sets of grazed quadrats. *Bouteloua* declined in basal area mainly during the first two-thirds of the study period, while *Stipa* decreased during the early and late years of the test. *Agropyron* decreased mainly during the second half of the experimental period, while *Koeleria* maintained or even increased its cover in the earlier years but declined

markedly during the drought years of 1934 to 1937. *Poa secunda* increased throughout the whole period, while *Eurotia* increased mainly during the later years of the experiment.

The changes in number of plants of the various species on the two series of quadrats did not correspond altogether with the shifts in basal area. *Stipa*, which decreased greatly in area, showed no significant change in number of plants. *Koeleria* which did not increase in area actually increased in number of plants. In the case of *Poa* and *Eurotia* the increase in density was accompanied by a corresponding increase in numbers, while *Artemisia* declined both in area and in numbers until 1938.

Data from a series of pantograph chart quadrats established in 1932, and from a group of area list quadrats laid down in 1931 were compiled also. The changes in plant cover were similar to those occurring on the 1928 and 1929 series after allowance was made for differences due to the later dates of establishment.

The data from 22 quadrats of the 1928 to 1938 series on areas of *Agropyron*-dominated vegetation are presented in table 16.

TABLE 16.—AVERAGE BASAL AREA OCCUPIED BY PRINCIPAL SPECIES IN QUADRATS ON GRAZED VEGETATION OF THE AGROPYRON TYPE

Species	Basal Area Occupied (p.c.)				Percentage Change (1928-1938)
	1928	1931	1934	1938	
Agropyron Smithii	8·03	5·77	5·42	4·33	−46
Koeleria cristata	0·62	0·54	0·50	0·40	−35
Poa secunda	0·16	0·68	1·22	1·52	+850
Total Grass Cover	9·81	6·99	7·14	6·25	−36
Artemisia frigida	0·53	0·42	0·39	0·25	−53
Phlox Hoodii	0·20	0·22	0·32	0·17	−15
Gutierrezia diversifolia	0·63	0·18	0·25	0·43	−32

NOTE—Statistical significance of differences is indicated by underlining of figure for percentage difference. Single underscoring indicates moderately significant differences (odds of 19:1 or greater) while double underlining indicates high significance (odds of 99:1 or greater).

Significant decreases occurred in basal area of *Agropyron* and in total grass cover, while the increase in *Poa* was highly significant. All three unpalatable weed species, *Artemisia, Phlox* and *Gutierrezia* decreased. Similar changes were recorded on a small group of quadrats of the 1929 to 1939 series.

The data indicated that the main decline in basal area of *Agropyron* and in total grass cover occurred during the first and last portions of the study period. *Koeleria* decreased significantly from 1934 to 1938.

Comparison of Results on Grazed and Ungrazed Vegetation

A comparison of changes in density of the principal species on grazed and ungrazed upland areas is presented in table 17. The data from several series of quadrats are included in this table, and differences in the response of certain species on the various sets of plots are indicated by the range shown in the figures for percentage change in density.

TABLE 17.—COMPARISON OF CHANGES IN AREA OCCUPIED BY PRINCIPAL SPECIES ON GRAZED AND UNGRAZED VEGETATION, 1928-1939

Species	Change in Basal Area Occupied	
	Grazed Areas	Ungrazed Areas
	p.c.	p.c.
Bouteloua gracilis	Decreased 30-37	Decreased 45-56
Stipa comata	Decreased 50-64	Decreased 37-46
Agropyron Smithii	Decreased 25-46	Decreased 30-42
Koeleria cristata	Slight decrease	Increased 50-58
Poa secunda	Increased 555	Increased 540
Total Grass Cover	Decreased 25-40	Decreased 35-44
Bouteloua : Stipa ratio	Increased significantly	No change.
Eurotia lanata	Increased 27-100	Increased 68-200
**Artemisia frigida*	No change.	Decreased 57
Phlox Hoodii	Increased 80-200	Increased 290.
Selaginella densa	Increased 27	Increased 37

*Figures for 1929 series of quadrats only.

The similarity in the response of most species on grazed and ungrazed areas indicates that climate rather than moderate grazing use was the principal factor affecting the plant cover during the period 1928 to 1939. Practically all of the major changes, including the decline in area occupied by *Bouteloua, Stipa, Agropyron* and total grass cover, as well as the marked increase in *Poa* occurred on both grazed and ungrazed areas. However, there were differences in the response of grazed and protected vegetation in regard to the density of *Koeleria, Eurotia* and *Artemisia,* as well as in the ratio of *Bouteloua* to *Stipa.*

The effects of climate during the period of study were evident mainly in the decrease in density of the three principal grasses, and in the increase of such low growing, short season forms as *Poa secunda, Phlox Hoodii* and *Selaginella densa.* Ellison and Woodfolk (5) reported a similar marked increase in *Poa secunda* on ranges depleted by drought at Miles City, Montana. *Artemisia frigida* declined to a very low level of density on both grazed and ungrazed quadrats at Manyberries during the worst drought years, and then increased rapidly during 1938 and 1939. This latter trend appeared to constitute the response of this species to a combination of more favourable climatic conditions together with decreased plant competition due to the decline in grass cover. Great decreases in the abundance of this species due to a series of dry years at Mandan, North Dakota, are described by Sarvis (10).

The changes in plant cover resulting from the effects of climate were apparently intensified by the fact that a high level of density was attained during the relatively favourable seasons from 1927 to 1930. In this connection it will be noted from tables 13 and 15 that a considerable decline in plant cover occurred prior to the beginning of the worst drought period of 1934. Evidently the cover of vegetation which had developed during these favourable years was too dense to be maintained under climatic conditions which were close to normal.

The effects of grazing in so far as they could be distinguished from those of climate, included an increase in the ratio of *Bouteloua* to *Stipa*, a detrimental influence on the density of *Koeleria* and *Eurotia* and a tendency to maintain the original cover of *Artemisia frigida*. The increase in the ratio of *Bouteloua* to *Stipa* indicated that grazing favoured the short grasses against *Stipa* and the other mid-grasses. *Koeleria* and *Eurotia* both increased on ungrazed areas in spite of drought conditions, but under grazing the former failed to maintain its density while the increase of the latter was checked considerably. *Artemisia frigida* declined considerably on both grazed and ungrazed areas during the drought period, but the decline was less and the subsequent recovery greater under grazing. That the above trends were definitely produced as a result of grazing is indicated by the results obtained in a study of different intensities of grazing reported earlier in this publication. In this experiment which covered a period of only 7 years, such features as the decline in density of the midgrasses, increase of the *Bouteloua-Stipa* ratio and maintenance of weed cover were most marked in the pasture grazed most heavily.

The changes occurring in the plant cover of the fields used in the grazing-capacity test during the years 1931-1937 (table 11) were noticeably less than those recorded on either moderately grazed or ungrazed areas during the period 1928-1939 (tables 13 and 15). The main reason for this difference was undoubtedly the fact that the principal changes in plant cover occurred during the periods 1928-1931 and 1937-1939.

Differences in the reaction of the principal species on grazed and ungrazed areas of the *Agropyron* consociation were relatively slight and involved the degree rather than the direction of change. Climatic factors appeared to be mainly responsible for the changes in plant cover which included a decline in density of *Agropyron*, total grass cover and forbs along with an increase in *Poa secunda*. *Agropyron* decreased a little more under grazing, while *Poa* increased more on grazed plots. In other words, climatic factors appeared to be mainly responsible for the decline in valuable forage species and the increase in *Poa secunda*, while grazing merely tended to intensify these trends.

Clipping tests conducted annually in both ungrazed exclosures and in temporarily protected areas in grazed fields indicated that the productivity of the vegetation was not lowered to nearly the same degree as was the density. Production was low in the drier years, but increased in proportion as moisture conditions improved, and there was no significant downward trend in yield during the period 1931 to 1939 (see table 9).

Conclusions

Results of the quadrat studies on grazed and ungrazed vegetation during a 12-year period brought out clearly the essentially dynamic nature of the plant cover. The density of the vegetation and the proportion of its component species did not remain static during the period of study, but responded appreciably to climatic fluctuations quite apart from the effects of grazing. Moderate grazing during this period of predominantly drought conditions tended to produce a plant cover containing a slightly greater proportion of short grasses to mid-grasses and a slightly greater cover of unpalatable weeds than were found on ungrazed areas exposed to the same climatic conditions. There was no evidence that any permanent change in the nature of the plant cover or in its productivity occurred as a result of either climate or grazing during the period of study. Rather the data indicated that a considerable degree of recovery occurred on both grazed and ungrazed plots in the years following the main drought period. Undoubtedly similar fluctuations in plant cover have occurred in the past and will occur again in response to climatic conditions. Moderate grazing, while intensifying to some extent the unfavour-

able effects of drought, seemed to be a factor of less importance than climate in modifying the plant cover. There was no evidence that any serious damage was done to the vegetation by grazing at a moderate rate even in the worst drought years. On the other hand, data obtained from fields grazed at different intensities indicated that the influence of heavy grazing is of as great or greater importance than that of climatic fluctuations. The principal species of the short-grass prairies are well adapted to withstand the harmful effects of recurring drought periods, but none of them can endure continuous close grazing for many years. Serious and progressive deterioration of the plant cover results from overgrazing over a period of years and climatic fluctuations while affecting the rate of depletion are not likely to alter the general trend.

GRAZING ROTATIONS

During the period of 1932 to 1937 deferred and rational grazing at rates of 20 and 30 acres per head for the 7-month grazing season (average April 8 to November 3) was tested in comparison with continuous grazing at these rates. This rotation was based on a system developed by workers in the United States, and involved the use of three fields of equal size for each intensity of grazing. Each pasture was grazed for approximately one-third of the grazing season. The rotational order during the six years of the experiment was as follows: the three fields in each set being designated as A, B and C.

Period	Year					
	1st	2nd	3rd	4th	5th	6th
Spring	A	B	C	B	A	C
Summer	B	A	B	C	C	A
Fall	C	C	A	A	B	B

Thus during a 6-year period each field had two seasons of spring grazing, two of summer and two of fall use. The object of the system was to allow the vegetation in each field to make its normal development in two years out of six, and to be protected from spring grazing in four years out of six. The two years of protection during the whole growing season were arranged to come consecutively so that any seedlings which might become started from seed produced in the first year of protection would have a chance to become established before being grazed.

The fields used for rotational grazing at 20 acres per head were 66·6 acres in size, while those grazed at the rate of 30 acres per head each contained 100 acres. Ten head of uniform, yearling Hereford heifers were placed in each set of pastures in 1932, and the same animals were grazed in the same fields in the subsequent years of the experiment. The heifers were bred at the age of two years, and in each succeeding year. Therefore, there were calves with the cows in the fields during the years 1934 to 1937 inclusive.

The pastures used for testing deferred and rotational grazing were adjacent to those used for the study of the effects of continuous grazing at different intensities. All the fields used in both experiments resembled each other closely in plant cover, topography and general grazing conditions. The response of both the plant cover and the cattle on the rotated fields was studied in the same manner as on the continuously grazed pastures. Quadrat studies, utilization surveys and determination of the gains made by the cattle were the principal methods used.

Results of Quadrat Studies

A summary of data obtained from the study of 25 area-list metre quadrats established on the field grazed rotationally at the rate of 20 acres per head is presented in table 18. Results from 18 similar plots located in the pasture grazed continuously at the same rate are included for purposes of comparison.

TABLE 18.—CHANGES IN PLANT COVER UNDER TWO DIFFERENT SYSTEMS OF GRAZING AT THE RATE OF TWENTY ACRES PER HEAD

Name of Species	Basal Area Occupied (in per cent)					
	Rotational Grazing			Continuous Grazing		
	1931	1937	Diff.	1931	1937	Diff.
			p.c.			p.c.
Bouteloua gracilis	3·34	3·22	−4	3·77	2·96	−21
Stipa comata	2·49	1·95	−26	2·62	1·86	−27
Agropyron Smithii	0·82	0·72	−12	0·86	0·78	−9
Koeleria cristata	0·30	0·66	+120	0·50	0·90	+80
Poa secunda	0·17	0·52	+206	0·05	0·54	+980
Other Grasses and Sedges	0·15	0·40	+170	0·06	0·16	+167
Total	7·27	7·37	+1·3	7·86	7·20	−8·5
Artemisia frigida	0·43	0·21	−51	0·62	0·41	−34
Phlox Hoodii	0·33	0·39	+18	0·78	0·70	−10
Selaginella densa	10·0	1·48	+48	15·0	20·0	+33

Statistical significance of changes is indicated by underlining of figure for percentage difference. Single underscoring indicates moderately significant differences (odds of 19:1 or greater), while double underlining indicates a high degree of significance (odds of 99:1 or greater).

It will be noted that while both the rotated and continuously grazed fields suffered somewhat from the heavy rate of use, the ill effects were more pronounced in the case of the latter. With the exception of *Agropyron Smithii*, none of the main forage grasses did as well under continuous use as under rotational grazing. The greater increase of *Poa secunda* which occurred on the continuously grazed pasture was a good indication of the depleted condition of the plant cover in that area. *Poa* increased in the rotated fields also, but not to such a marked extent.

Results of quadrat studies on the fields grazed rotationally at the rate of 30 acres per head, along with data for the pasture grazed continuously at the same rate are included in table 19. Thirty area-list quadrats were studied in the rotated fields and 27 in the continuously grazed area.

The considerable differences in the response of the vegetation under the two systems of grazing at the rate of 30 acres per head, were nearly all in favour of the rotated fields. The main forage species, including both *Bouteloua* and the highly productive mid-grasses (*Stipa*, *Agropyron* and *Koeleria*), all did better under rotational use. Associated with the decline in valuable forage species on the continuously grazed pasture was a great increase in *Poa secunda*. A much smaller increase of *Poa* occurred in the rotated fields. During the period of the study the average forage yield index of the quadrats on the rotated pastures increased slightly, by 13 per cent, while the yield index of the quadrats grazed continuously declined slightly.

TABLE 19.—CHANGES IN PLANT COVER UNDER TWO DIFFERENT SYSTEMS OF GRAZING AT THE RATE OF THIRTY ACRES PER HEAD.

Name of Species	Basal Area Occupied (in per cent)					
	Rotational Grazing			Continuous Grazing		
	1931	1937	Diff.	1931	1937	Diff.
			p.c.			p.c.
Bouteloua gracilis	3·16	3·03	−4	3·37	2·79	−17
Stipa comata	2·75	2·47	−10	1·79	1·41	−21
Agropyron Smithii	0·70	0·91	+30	1·22	1·25	−2
Koeleria cristata	0·32	0·88	+175	0·43	0·69	+60
Poa secunda	0·12	0·39	+225	0·10	0·64	+540
Other Grasses and Sedges	0·36	0·46	+31	0·75	0·84	+12
Total	7·40	8·14	+10	7·66	7·62	−0·5
Artemisia frigida	0·53	0·22	−58	0·72	0·22	−69
Phlox Hoodii	0·32	0·42	+31	0·49	0·61	+24
Selaginella densa	6·50	13·7	+110	12·0	18·0	+50

Statistical significance of changes is indicated by underlining of figure for percentage difference. Single underscoring indicates moderately significant differences (odds of 19:1 or greater), while double underlining indicates a high degree of significance (odds of 99:1 or greater).

Altogether the quadrat data indicated that the system of deferred and rotational grazing was superior to continuous use so far as the effects on the vegetation were concerned. This was most evident in the case of pastures grazed at a rate (30 acres per head) which was somewhere near their true grazing capacity. On fields which were grazed heavily, at the rate of 20 acres per head, there was less difference in the response of the plant cover under the two systems of grazing.

Forage Utilization

Utilization surveys made annually on both rotated and continuously grazed fields did not reveal any significant differences in forage carryover under the two systems of grazing. In all of the pastures used at the rate of 20 acres per head the carryover was below 25 per cent in 4 out of 6 years of the experiment. There was practically no available forage left in these fields at the close of the grazing season in the drier years. In the pastures grazed at the rate of 30 acres per head the carryover fell below 25 per cent only during the two worst years of drought, and averaged over 30 per cent during the remaining 4 years. Evidently the degree of forage utilization was determined mainly by the rate of stocking rather than by the system of grazing which was practised.

Response of Cattle to Two Different Systems of Grazing.

Data on the response of the cattle were obtained mainly by individual weighings made at regular intervals during each year of the study. A summary of the results is presented in table 20.

TABLE 20.—AVERAGE GAINS IN WEIGHT OF CATTLE UNDER DIFFERENT SYSTEMS AND INTENSITIES OF GRAZING

Grazing Method and Intensity		Average Gain in Weight of Cows, Weaning Weight of Calves (all in pounds).						
		1932	1933	1934	1935	1936	1937	Average
Rotational at 20 acres per head	Cows	267	292	118	92	79	21	145
	Calves	......	......	355	369	293	307	331
Continuous at 20 acres per head	Cows	319	284	136	141	22	45	158
	Calves	......	......	339	389	322	363	353
Rotational at 30 acres per head	Cows	296	296	169	163	198	73	199·2
	Calves	......	......	347	360	347	358	353
Continuous at 30 acres per head	Cows	334	307	120	159	176	102	199·5
	Calves	......	......	405	425	359	390	395

Minimum significant differences in average gain for the various lots of cows are as follows: 34 pounds for rotational versus continuous at 20 acres (also for rotational at 30 versus rotational at 20). For calves, the corresponding figures are 41 pounds for rotational versus continuous at 20 acres, 44 pounds for rotational versus continuous at 30 acres.

There was no significant difference in the gains made by the cows nor in the weaning weights of the calves under the two systems of grazing at the 20-acre rate. At the 30-acre rate, however, the average weaning weight of calves in the rotated fields was significantly lower than that of the calves in the continuously grazed areas. The average gains of the cows under the two systems of grazing at the 30-acre rate were identical.

Discussion of Results

In view of the good response of the plant cover to deferred and rotational grazing, particularly at the rate of 30 acres per head, it might have been expected that both cows and calves would thrive at least as well on rotated as on continuously grazed areas. However, in assessing the results which were obtained it should be remembered that the experiment covered a relatively short period of time, and thus the cumulative effects of the two systems of grazing upon both vegetation and the gains of the cattle were not fully determined.

One factor which may well have affected adversely the response of the animals in the rotated fields was the small size of these pastures. The fields used for rotational grazing at the rate of 20 acres per head were only 66·6 acres in size, and those used at the 30-acre rate were 100 acres in extent. The pastures used for continuous grazing at these two rates were larger, one being 200 acres in extent and the other including 300 acres. It was observed that the cattle in the 66·6 and 100 acre fields were restless and did an unusual amount of walking along the fence lines. This effect was intensified by the fact that the rotation involved moving the animals into three different fields during the 7-month grazing season. These factors would probably have been of little importance for cattle accustomed to small fields and frequent moves from one pasture to another, but they did seem to have significance with the type of range cattle used in this experiment.

Results obtained by Sarvis (9, 10) on mixed prairie vegetation at Mandan, North Dakota were more conclusive with regard to deferred and rotational grazing. It was found that approximately 5 acres per head were required for the 5-month grazing season under rotational grazing, as compared with a minimum of 7 acres per head on continuously grazed fields. The gains made by cattle grazing at the rate of 5 acres per head on rotated fields

were better than those made under continuous grazing at the same rate, but slightly less than those made under continuous grazing at 7 acres per head. The main benefit of the rotational system at Mandan appeared to be in reducing the amount of range required per animal and in increasing the number of pounds of beef produced per acre rather than in producing maximum individual gains.

The data from the Manyberries experiment cannot be considered as being conclusive, due to the relatively short duration of the test and to the possibility that the small size of some of the rotational pastures exerted a detrimental influence on the response of the cattle. Furthermore, as Sarvis (10) has pointed out, the beneficial effects of deferred and rotational grazing are probably most evident in the restoration of overgrazed ranges rather than in the utilization of pastures which are in a highly productive condition. The fields used for the test of rotational grazing at Manyberries were all in good condition at the start of the experiment. The data obtained to date indicate that the system of deferred and rotational grazing tested was of some benefit to the plant cover, but gains made by the cattle were not affected greatly. While further testing would be necessary to determine more conclusively the merits of this particular type of rotational grazing, it does not appear likely that the benefits obtained would be sufficient to offset the increased costs due to the extra fencing and water development required. In addition to the increased costs and labour connected with this three-field rotation, there were certain weaknesses in the system when applied to the pastures at Manyberries. The most detrimental feature was the very heavy use of the spring-grazed field which had to carry three times the normal number of cattle during one year out of every three. Another point was that one field each year was not grazed at all until fall. There was an appreciable decline in both the quality and the quantity of the available forage on fields which were not grazed until fall. This was due to the normal seasonal decline in nutritive value of the vegetation and to the loss of forage caused by the dropping of cured leaves, seeds, etc. The rotation did not appear to be very effective in inducing natural reseeding. The reseeding which did occur came mainly during years when moisture conditions were better than average, and appeared to be affected mainly by the intensity of grazing rather than by the system practised.

Other Grazing Rotations

While no rotation other than the three-field system previously discussed was tested under grazing, a two-field rotation conducted on clipped plots gave promising results. This latter system which was developed in an effort to overcome some of the disadvantages of the three-field rotation, involved the division of the grazing season into three periods, designated as spring, summer and fall, and the use of two fields (A and B). In the rotation, field A would be grazed in the spring and fall periods, and field B would be used in the summer only during the first year. In the second year the order would be reversed, with field B grazed in spring and fall, field A in the summer. It was found that by terminating the spring period about at the end of May, considerable subsequent growth usually occurred on the spring-grazed field. At the same time, protection of the summer-grazed field until the first of June allowed the vegetation time to make most of its normal development before being exposed to grazing. A summary of the yields obtained on plots clipped to simulate this rotation is presented in table 21.

Plots clipped according to the rotation outyielded their continuously-clipped checks in each of the five years during which the test was conducted. The average increase of the rotated plots over those clipped to simulate continuous grazing was 25·5 per cent. On the other hand, yields from clipped

TABLE 21.—FORAGE YIELD OF PLOTS UNDER ROTATIONAL AND CONTINUOUS CLIPPING 1935-1939 INCLUSIVE

Treatment	Yield in Pounds per Acre of Air-Dry Forage					
	1935	1936	1937	1938	1939	Average
Rotationally Clipped						
Series A	492	250	309	697	424	434
Series B	468	255	339	451	468	396
Averages of A and B	480	252·5	324	574	446	415
Average of Continuously Clipped Checks	382	161	212	500	399	331

Minimum significant difference in average yield of the two treatments is 49 pounds.

plots used to test the three-field deferred and rotational system were not significantly higher than those from check plots clipped to simulate continuous use.

Altogether the two-field system of deferred and rotational grazing just described appeared to be better suited to the seasonal development and life cycle of the principal forage species than were either the three-field rotation or continuous use. However, a test on grazed fields for a period of years would be necessary to determine the value of this system under actual grazing conditions. This two-field rotation would be cheaper and simpler to use than the three-field system.

While few ranchers on the short-grass prairies practise rotational grazing as such, a considerable amount of this type of use results from the practice of establishing separate fields for different classes of live stock.

MAINTENANCE AND MANAGEMENT OF RANGE PASTURES

Under this heading are grouped the results from a number of studies differing considerably in nature, but all having a bearing on the management of short-grass prairie ranges.

Effects of Overgrazing

Due to the fact that grazing at different intensities was practised for a period of only seven years and that the forage cover of the experimental pastures was in good condition at the beginning of the test, little opportunity was afforded for detailed study of the effects of severe overgrazing. However, the data which were obtained along with observations made both on the Station pastures and on other range areas yielded a clear general picture of the effects of different degrees of overgrazing.

The initial effects of overgrazing included a decline in the density, vigour and productivity of the principal forage plants, particularly the mid-grasses. Short-grass species were less affected by moderate overgrazing. Along with the decline in palatable plants occurred an increase in certain less palatable and productive grasses and forbs. This first stage of overgrazing was illustrated on the fields grazed at the rate of 20 acres per head in the grazing-capacity test. Data from the pantograph quadrats, which covered the period of the experiment most fully revealed significant changes after seven years of heavy use. The bunch mid-grasses, *Stipa comata* and *Koeleria cristata* were affected most severely, their average density declining by 37 and 50 per cent respectively. The two other principal forage grasses, *Bouteloua gracilis* and *Agropyron*

Smithii declined also, but not to the same extent as the above-mentioned species. *Poa secunda,* a grass of low forage value, increased by 90 per cent, while the unpalatable forb *Artemisia frigida* increased by 117 per cent.

Observations on comparable range areas which had been overgrazed more severely indicated that a further reduction in palatable species and increase in unpalatable forms occurred. The mid-grasses became very sparse and stunted, while even the short-grass species declined in density and vigour. This stage was usually marked by a great increase in forbs such as *Artemisia frigida, Gutierrezia diversifolia, Opuntia polyacantha* and *Phlox Hoodii.* An example of this condition is presented in Fig. 9.

Fig. 9.—Depleted range area dominated by *Artemisia frigida* (pasture sage) and other unpalatable species as a result of severe overgrazing. The perennial grass cover on this pasture is very sparse.

Data obtained in the grazing-capacity test indicated that the rate of depletion on pastures of the type studied was fairly slow during the first few years of heavy use, and recovery rather rapid when overgrazing ceased. For instance, the forage cover of fields grazed at the rate of 20 acres per head declined considerably, but did not become severely depleted during a seven-year period. The productivity of these pastures increased greatly during two subsequent years of lighter use.

On the other hand, observations made on other range areas indicated that pastures which had become severely depleted usually required many years for recovery, especially if climatic conditions were unfavourable.

It was found that considerable caution had to be used in interpreting the abundance of unpalatable species as indicators of overgrazing. Quadrat studies at the Manyberries Station indicated that the area occupied by many species usually regarded as reliable indicators of overgrazing was influenced strongly by climatic fluctuations as well as by grazing use. For instance, during the

drought period of 1931-1937, *Artemisia frigida* decreased not only on protected areas and lightly grazed fields, but also on heavily grazed pastures. This species increased greatly in abundance on both moderately and heavily grazed areas in the relatively favourable seasons of 1938 and 1939, which followed the drought years. The marked increase in abundance of *Poa secunda* which constituted perhaps the most conspicuous change occurring in the short-grass prairie vegetation during the period from 1928 to 1939, occurred even on areas which were grazed lightly or not at all. However, the increase in *Poa* was greatest on heavily grazed fields, and to this extent the abundance of the species could be considered as an indication of overgrazing.

Best results in evaluating the condition of any piece of range with respect to its grazing use were obtained when all the available evidence was considered, including the vigour, reproduction and degree of utilization of both palatable and weed species, along with the gains made by the live stock using the area.

The extent to which relatively unpalatable species such as *Artemisia frigida* and *A. cana* were utilized (by cattle or horses) during the regular grazing season was usually a reliable criterion of pasture use. Where such species were eaten to any considerable extent it was usually safe to conclude that the pasture in question was being overgrazed. The gains made by live stock constitute a good indication of overgrazing. In the brief grazing-capacity test conducted at Manyberries the gains of cattle on the heavily grazed pastures were significantly lower than those made by comparable animals on moderately grazed fields. Long-term results reported by Sarvis (10) in North Dakota confirm these findings.

Another detrimental effect of overgrazing was accelerated erosion of the soil by both water and wind. The compact, moderately fine soils of the short-grass prairie area erode rather readily when their grass cover becomes depleted. Plants weakened by overgrazing are not so effective in checking erosion as are those in vigorous condition, while the forbs and shrubby forms which become so abundant on badly depleted pastures are not usually so efficient in binding the soil as are the grasses.

Evidences of local erosion were often observed on cattle paths and around watering places even under conditions of moderate grazing. With overgrazing this tendency became much more marked and widespread.

The principal remedy for pasture erosion is the obvious one of reducing the number of cattle being grazed on the area to the number warranted by the volume of available forage. Still greater reduction of grazing intensity for a few seasons along with the use of some form of grazing rotation is often advisable, in order to hasten restoration of the forage cover. Local erosion along stock trails and around watering places can be minimized by provision of an adequate number of well distributed supplies of water, by the proper use of salt and by care in the management of the live stock generally.

The trampling done by live stock under conditions of moderate grazing did not usually produce any marked detrimental effects on short-grass prairie vegetation, but considerable damage was done in this way on overgrazed pastures. The harmful effects of excessive trampling were most evident during the spring months. At this time the soil was usually moist and soft on top, the vegetation was in the early growth stages and the cattle tended to wander extensively in search of new grass, particularly on depleted areas. On the finer soils heavy trampling resulted in undue compacting of the surface soil, with a consequent decrease in moisture-absorbing powers and an increased rate of water loss due to run-off and evaporation. On soils of coarser texture, erosion was accelerated greatly by excessive trampling.

The ravages of rodent and insect pests were usually greater on overgrazed fields than on pastures which were utilized conservatively. The prairie gopher (*Citellus richardsonii*) destroyed considerable forage on depleted pastures but

did not appear to do much harm under conditions of moderate grazing. Grasshoppers flourished on overgrazed areas, where conditions for completing their life cycle were much better than on well grassed land. The amount of forage taken by these various pests on overgrazed pastures was not only greater in actual amount than on moderately utilized areas, but was also of much greater relative importance, since in the former case all the available forage was badly needed by the live stock.

Effects of Distance from Water Upon Uniformity of Grazing

The importance of supplying an adequate number of watering places for live stock on the range was realized at the start of the work at the Manyberries Station, and steps were taken to remedy the deficiency which existed on the land chosen for the experimental area. It was found that satisfactory watering places could be made by constructing earthen dams at suitable locations in coulees, and a large number of reservoirs of this type were developed. Sufficient watering places were established on the experimental range to bring practically all points within one and a half miles of water. The beneficial effects of this program were seen in a general way in the excellent gains made by the cattle, and in the relatively uniform utilization of the various parts of the range.

Due to the well-watered condition of the experimental area, no opportunity was offorded for studying the detrimental effects of a shortage of watering places. However, data were obtained on the changes in plant cover occurring on quadrats located at different distances up to one and a half miles from water. Permanent metre quadrats located on 4 large fields grazed at the very moderate rate of 40 acres per head for the 7-month season were used in this study. These quadrats were classified into three groups, namely, those located within one half mile of a watering place, those within one mile and those situated a distance greater than one mile. The great majority of the third class were located within one and a half miles from water. Analysis of the changes in plant cover occurring on these quadrats during the period 1928 to 1938 showed that the area occupied by the 2 main grasses, *Bouteloua* and *Stipa* decreased considerably in all 3 groups, due to climatic conditions. However, *Bouteloua* decreased only 22 per cent in the quadrats located closest to water as compared with 32 per cent in the quadrats located one half to one mile from water and 35 per cent in those situated at distances greater than one mile. Other studies of the effects of grazing indicated that *Bouteloua* usually decreased less under moderate grazing than under light use. Hence the response of this species indicated that the intensity of grazing had been probably slightly heavier on areas relatively close to water. However, the data for changes in area occupied by *Stipa* showed no appreciable difference between the response of the three groups of quadrats. General observation revealed that during hot, dry weather the cattle did tend to graze fairly close to the watering places, but this tendency appeared to be offset largely by the grazing of more distant parts of the range during cooler periods. Under the conditions of the experiment, it appeared that the range was grazed fairly uniformly up to a distance of one and a half miles from water.

Observations made on other range areas showed clearly the detrimental effects on both vegetation and live stock caused by a lack of well-distributed watering places. Overgrazing of the land immediately adjacent to water and under utilization of more distant range was found to occur with cattle whenever the distance between watering places exceeded four miles. Cattle failed to make normal gains under such conditions.

Effects of Different Frequencies and Dates of Clipping

The effects of clipping at different intervals during the grazing season were tested on temporarily protected plots on grazed fields. These plots were selected

newly each year, using fields which were not to be grazed until fall. One series of these plots was clipped 3 times during the season, beginning when the grasses were in the medium leaf stage. A second series was clipped first when the plants were in the sheath stage, and again in the fall. A third set was clipped only once, in the fall. Sites for this study were selected on vegetation dominated by *Bouteloua gracilis, Stipa comata* and *Agropyron Smithii* respectively. A summary of the results obtained is presented in table 22.

TABLE 22.—AVERAGE YIELD OF FORAGE FROM PLOTS CLIPPED AT VARIOUS INTERVALS DURING THE GRAZING SEASON, 1934-1939 INCLUSIVE

Dominant Species	Yield of Air-Dry Forage in Pounds, per Acre			
	Plots Clipped 3 times	Plots Clipped twice	Plots Clipped once	Average
Bouteloua gracilis	169	171	148	163
Stipa comata	258	312	246	272
Agropyron Smithii	333	346	336	338
Average	253	276	243	258

NOTE.—Minimum significant difference between species or treatments equals 52 pounds per acre.

There was considerable difference in the response of the three species to the clipping treatment. Statistical analysis indicated that in the case of *Stipa* the yield of the plots clipped twice each season was significantly higher than that of either of the other two series. No significant differences in yield occurred among any of the three series on the plots dominated by *Agropyron Smithii* or *Bouteloua.*

When the average yields of plots dominated by each of the three species were compared, it was found that *Agropyron* outyielded *Stipa* significantly under two out of three systems of clipping, while the latter in turn yielded significantly more than did *Bouteloua,* regardless of the method of treatment.

The results of this study emphasize the points that (1) removal of foliage early in the spring and at frequent intervals thereafter resulted in decreased yields, particularly in the case of the bunch grasses. (2) There was a considerable loss of forage on areas which are not cut or grazed until fall as compared with those which are utilized during the summer. (3) Differences in the yields of vegetation dominated by each of the three main grasses tended to persist under a variety of clipping or grazing treatments. However, the yield of areas dominated by *Stipa* was lowered more by frequent clipping than was that of vegetation dominated by either *Bouteloua* or *Agropyron.*

Effects of Burning Range Pastures

Studies of the effects of fire on range areas were made both on experimentally burned plots and on pastures where fires had occurred. On the experimental plots it was found that the yield of areas burned in the spring was reduced by approximately 50 per cent during that year, and by about 15 per cent in the following year. After that time there was not significant reduction in yield as compared with adjacent unburned plots. Fall burning caused a decrease of about 30 per cent in forage production in the following year and no significant reduction after that time. The decline in yield of both spring and fall burned plots was greater on vegetation of the *Agropyron* type than on the upland communities dominated by *Bouteloua* and *Stipa.*

Observations on pastures which had been burned indicated that the recovery of the vegetation on these areas was not so rapid as on the ungrazed experimental plots. The time required for a burned and grazed field to regain normal productivity after fire was at least three to five years.

The decrease in yield following burning was due mainly to stunted growth rather than to killing of plants. Removal of the cover of old grass by fire resulted in increased soil temperatures and an increased rate of water loss from both ground and vegetation. Damage caused by trampling of live stock was greater on burned than on unburned areas. The botanical composition of the plant cover was affected to some extent, there being an increase of unpalatable weed species, especially in the *Agropyron* consociation.

From the standpoint of grazing, the detrimental effects of burning included not only the reduction in current yield of forage, but also the destruction of the cover of old grass. This carryover of cured vegetation, usually present on moderately grazed pastures, is an important part of the range forage crop. It is particularly valuable in the early part of the grazing season to supplement the young growth which is too watery and high in protein at that time to constitute a satisfactory feed for cattle when eaten alone.

The Effects of Manuring Range Pastures

The effects of barnyard manure applied at various intervals on the productivity of different types of range vegetation were studied during the period 1928 to 1939. One set of plots on typical upland (*Bouteloua-Stipa*) vegetation and sandy loam soil was treated in the fall of 1928 with well-rotted manure at the rate of approximately 12 tons per acre. These plots were not fertilized again. In 1932 a regular series of treatments, all at the 12-ton rate, was started both on the upland site and on an area of silt loam soil dominated by *Agropyron Smithii*. Three different treatments were tested at each site, namely, manuring every second year, every third year and every fourth year. Yield tests were taken subsequently on both fertilized plots and untreated checks. A summary of the results obtained is included in table 23. Yields were obtained for 5 years in all cases except for the plots treated in 1928 only. The latter were sampled for 6 years, beginning in 1933.

TABLE 23.—EFFECT OF APPLICATIONS OF BARNYARD MANURE AT VARIOUS INTERVALS ON THE YIELD OF NATIVE VEGETATION

Treatment	Average Forage Yield in Pounds Per Acre-Dry Weight					
	Bouteloua-Stipa Vegetation			Agropyron Vegetation		
	Treated	Untreated	Diff.	Treated	Untreated	Diff.
			p.c.			p.c.
Manured every second year.	1248	370	+237	727	424	+71
Manured every third year..	968	336	+188	683	422	+62
Manured every fourth year.	871	358	+143	625	424	+47
*Manured in 1928 only......	850	420	+102	....	....	....

*Average yield for period 1933-1938 inclusive.

While the greatest increase in yield was obtained on the plots fertilized most frequently, the best results in relation to the work done and material used were given by the plots treated in 1928 only. In 1939, eleven years after the application of manure was made, these plots yielded slightly more than twice as much forage as did adjacent untreated checks.

The response of plots on areas dominated by *Agropyron Smithii* was less marked than that which occurred on the upland vegetation. However, there were significant increases in yield on all the treated plots.

While manuring of range lands would not be practicable over large areas, it does appear to be a useful method for increasing the yield of small pastures of particular importance. The grazing capacity of areas close to the ranch headquarters where it is often desirable to keep considerable numbers of stock for a portion of the year could be increased greatly by the use of manure which is usually available in fair quantities. Judging by the data reported here, best results in relation to the effort and material used may be expected from manuring areas of upland vegetation on relatively light soils at intervals of about ten years.

SUMMARY AND CONCLUSIONS

This bulletin presents the results obtained in studies of the native vegetation and its utilization at the Dominion Range Experiment Station, Manyberries, Alta., during the period 1928 to 1939 inclusive. Projects conducted at this Station included studies of the response of cattle to various range management practices as well as investigations of the plant cover.

The experimental area consisted of approximately 18,000 acres of native grassland. The topography is relatively level, the main relief occurring in the form of coulees and areas of badlands. The soils of the region belong to the Brown Zonal Group, and are mainly of sandy loam texture. Distinctive soil features include the presence of numerous shallow eroded pits known as " blow-outs " on the surface in many places, and the occurrence of a layer of carbonate concentration at an average depth of only one foot.

The climate of the area is characterized by scanty precipitation, a high rate of evaporation, great extremes of temperature, high and frequent winds and long hours of sunshine. Precipitation during the years 1928 to 1939 averaged 10·7 inches annually, with half this amount falling during the period April 1 to July 31. The average seasonal evaporation (May to September inclusive) was 33 inches.

The vegetation of the area consists of a xeric phase of the mixed prairie. designated as short-grass prairie. This association which extends over large areas in the drier portions of southern Alberta and southwestern Saskatchewan, is characterized by an abundance of short-grass forms and by the stunted growth of the mid-grasses. The principal species in relative order of basal area occupied are *Bouteloua gracilis* (*grama grass*), *Stipa comata* (speargrass), *Agropyron Smithii* (western wheatgrass), *Koeleria cristata* (Junegrass), *Poa secunda* (Sandberg's bluegrass), and *Carex filifolia* (niggerwool). The most common forbs are *Artemisia frigida* (pasture sage) and *Phlox Hoodii* (dwarf phlox). *Selaginella densa* (little club-moss) is very abundant over much of the area. *Bouteloua* and *Stipa* are the main dominants on upland areas of medium textured soils, while *Agropyron Smithii* is the principal species on silts or clay loams, especially in low-lying areas. The grasses mentioned, along with two shrubby forms, *Eurotia lanata* (winter fat) and *Atriplex Nuttallii* (salt sage), produced the bulk of the palatable forage on the area. Studies of the yielding ability of the principal forage species showed that *Stipa comata* produced more forage than any other species on the experimental area. Next in order of importance were *Agropyron*, *Bouteloua*, *Koeleria* and *Eurotia*.

Studies of the relation of climate to plant growth revealed that soil moisture is the principal limiting factor, with air and soil temperatures being of prime importance for only a short interval in the spring. The dominant species are low-growing perennial grasses with extensive and finely branched root systems. Growth is rapid during the spring and early summer months, and the vegetation

normally completes its seasonal development prior to the beginning of the regular midsummer drought. There is a rather close relationship between the seasonal ratio of precipitation to evaporation and annual forage yields.

A 7-year test of grazing capacity was made at intensities of 20, 30 and 40 acres per head respectively for the 7-month grazing season (April 1 to October 31). Results indicated that the true grazing capacity of the area studied was slightly more than 30 acres per head. At the rate of 20 acres per head the cattle failed to make normal gains, while the plant cover showed signs of deterioration. The mid-grass species such as *Stipa comata* suffered more from heavy grazing than did *Bouteloua gracilis* and other short-grass forms.

Significant changes in plant cover occurred on the experimental area during the period of study as a result of climatic fluctuations, quite apart from grazing use. The density of the vegetation reached a high level during the relatively favourable seasons of 1928 to 1929, and declined during the following decade which was marked by drought conditions. All of the principal dominants decreased in basal area during the period 1930 to 1939 with the exception of *Poa secunda*. This short-season species increased greatly as the stand of the other dominants became thinner. It was apparent that the composition of short-grass prairie vegetation is in a state of only relative equilibrium and that appreciable changes are occurring continually in response to variations in climatic conditions.

During the period 1932 to 1937 deferred and rotational grazing at rates of 20 and 30 acres per head for the 7-month grazing season was tested in comparison with continuous grazing at these rates. The rotation involved the use of three fields of equal size, and the division of the grazing season into three approximately equal periods. Results indicated that the rotation was superior to continuous use so far as effects on the plant cover were concerned. The vegetation of the fields grazed in rotation at the rate of 30 acres per head suffered little deterioration in spite of unfavourable climatic conditions. No apparent advantage to the cattle was derived from the rotation. However, the experiment was not conducted for a sufficiently long period for the full effect of the system to be determined. The small size of the rotated pastures appeared to be a detrimental factor of considerable importance. While results were not altogether conclusive, it did not appear likely that the benefits derived from this particular rotation would compensate for the expense due to the extra fencing and water development required. Another rotation, involving only 2 fields, gave better results in clipping tests, but was not tried under actual grazing.

Studies were made of the effect of various practices on the maintenance of the forage cover both on the experimental area and in other parts of the short-grass prairie area. The effects of overgrazing were found to consist chiefly of a progressive decrease in the abundance, vigour and yield of the more palatable species, associated with a corresponding increase in unpalatable weeds. Soil erosion and damage due to trampling by live stock and to the depredations of rodent and insect pests were all increased under over-grazed conditions. Studies of the effect of distance from water upon uniformity of grazing indicated that there was some tendency to graze more heavily close to the sources of water. However, grazing was fairly uniform on the experimental area where practically all parts of the range were within one and a half miles from water.

Burning of range pastures in either spring or fall caused reductions in forage yield, and from 3 to 5 years was usually required for complete recovery under conditions of moderate grazing.

Marked increases in forage yield were obtained by applications of barnyard manure, even at intervals of as long as ten years. Results were much more marked on sandy upland soils than on silt loam lowland areas.

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